



# **Massachusetts Military Reservation**

## ***PLUME RESPONSE PROGRAM***

### ***Final FS-28 and FS-29 Groundwater Feasibility Study***

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*Prepared for:*  
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**Installation Restoration Program**  
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## ACRONYMS AND ABBREVIATIONS

AFCEE	Air Force Center for Environmental Excellence
ANG	Air National Guard
ARARs	applicable or relevant and appropriate requirements
atm	atmosphere
atmosphere- m <sup>3</sup> /mol	atmosphere – cubic meter per mole
bgs	<i>below ground surface</i>
CCl <sub>4</sub>	carbon tetrachloride
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
cis-DCE	cis-dichloroethene
CMR	Code of Massachusetts Regulations
COC	contaminant of concern
COPC	contaminant of potential concern
CS-#	chemical spill, as in CS-10
CWSW	Coonamessett Water Supply Well
DEP	Massachusetts Department of Environmental Protection
DO	dissolved oxygen
DOE	Department of Energy
EDB	ethylene dibromide (1,2-dibromoethane)
EE/CA	<i>engineering evaluation and cost analysis</i>
EPA	U.S. Environmental Protection Agency
ETD	extraction, treatment and discharge
ETR	extraction, treatment and reinjection
FS	feasibility study

## ACRONYMS AND ABBREVIATIONS

FS-#	fuel spill, as in FS-28
ft <sup>3</sup>	cubic feet
GAC	granular-activated carbon
GC/MS	gas chromatography/mass spectroscopy
gpm	gallons per minute
HEC	hazard equivalent concentration
HI	hazard index
kg	kilogram
K <sub>oc</sub>	Organic Carbon Partition Coefficient
MCL	maximum contaminant level
MDL	method detection limit
mg/L	milligrams per liter
MMCL	Massachusetts maximum contaminant level
MMR	Massachusetts Military Reservation
MNA	monitored natural attenuation
msl	mean sea level
MW	monitoring well
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NPDES	National Pollutant Discharge Elimination System
ORP	oxidation reduction potential
ORD-EPA	Office of Research and Development, United States Environmental Protection Agency
O&M	operations and maintenance
1,1,2,2,-TCA	1,1,2,2-tetrachloroethane
PCE	tetrachloroethene

## ACRONYMS AND ABBREVIATIONS

RAO	remedial action objective
REC	risk equivalent concentration
RI	remedial investigation
RI/FS	Remedial Investigation/Feasibility Study
RME	reasonable maximum exposure
RPM	remedial project managers
ROD	record of decision
SD-#	storm drain, as in SD-5
SDWA	Safe Drinking Water Act
SWOU	Southwest Operable Unit
TCE	trichloroethene
TCLP	Toxicity Characteristic Leaching Procedure
TIC	total installed cost
UV/OX	ultraviolet/oxidation
VOCs	volatile organic compounds
µg/L	micrograms per liter

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## EXECUTIVE SUMMARY

This feasibility study (FS) describes the evaluation of remedial alternatives for groundwater contamination present in the Fuel Spill-28 (FS-28) and Fuel Spill-29 (FS-29) plumes, which lie within the Southwest Operable Unit (SWOU). The contaminant of concern in the FS-28 plume is ethylene dibromide (EDB). The contaminants of concern in the FS-29 plume are EDB and carbon tetrachloride.

The *Final Southwest Operable Unit Remedial Investigation* (AFCEE 1999c) concluded that future residential use of area groundwater could pose a cancer risk greater than regulatory limits. There are no current unacceptable human health risks associated with swimming in or consuming fish caught from Coonamessett Pond or Deep Pond (surface water bodies potentially impacted by these plumes). Because ecological risk is primarily attributable to natural levels of metals in emerging groundwater and not Massachusetts Military Reservation-related organic contaminants, human health risk is the primary driver for remedial action.

Under the Remedial Investigation/Feasibility Study (RI/FS) process, remedial action objectives (RAOs) have been developed for each plume. These objectives call for:

- the prevention or reduction of residential exposure to groundwater contaminants of concern in excess of drinking water standards or risk-based thresholds,
- restoration of the aquifer to its beneficial uses within a reasonable time,
- the prevention of worker and child and adult wader contact with Coonamessett River water containing unacceptable concentrations of EDB (FS-28 plume only),
- the prevention or reduction of ingestion of fish exposed to Coonamessett River water containing unacceptable concentrations of EDB (FS-28 plume only).

Technologies determined to be of potential use in reaching these objectives include: vertical extraction wells, greensand filtration, settlers and clarifiers, activated carbon adsorption, mobile carbon treatment, reinjection wells, infiltration galleries, and recirculating wells. Remedial alternatives that rely on these technologies have been developed, screened, and evaluated. These alternatives range from long-term monitoring to full plume capture and treatment.



To mitigate potential risks to human health by the EDB in the FS-28 plume, the Air Force Center for Environmental Excellence (AFCEE) has already implemented time-critical and non-time-critical removal actions. These actions include installing a municipal well protection system, connecting residents near the plume to municipal water, separating the cranberry bogs from the river system, installing systems to provide agricultural users with clean water, and installing an extraction, treatment and discharge system at the leading edge of the plume. If not for the existing treatment system, the FS-28 plume would discharge to the Coonamessett River. Additional alternatives are being considered that provide quicker aquifer restoration. Remedial alternatives presented for the FS-28 plume include continued operation of existing treatment facilities, additional extraction, treatment and reinjection north of Coonamessett Pond, and additional extraction and treatment south of the pond with discharge to Coonamessett Pond and Coonamessett River.

The FS-29 plume is a large body of very dilute contamination. Remedial alternatives presented include long-term monitoring, institutional and engineering controls, plume capture and treatment, and capture and treatment of the central portion of the plume.

The goal of this document is to present the technical information on which decisions for remedial action will be based. Remedial alternatives presented in this document have been evaluated on the basis of:

- overall protection of human health and the environment,
- compliance with applicable or relevant and appropriate requirements,
- long-term effectiveness,
- reduction of toxicity, mobility or volume through treatment,
- short-term effectiveness,
- implementability, and
- cost.

Other important decision criteria that fall under state and community acceptance will be taken into consideration following the release of a proposed plan outlining

preferred remedies for these two plumes. A public meeting will be held on February 10, 2000 to present the proposed plan. The public comment period on the proposed plan will take place from February 11 through March 10, 2000.

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## 1.0 INTRODUCTION

This *Draft FS-28 and FS-29 Groundwater Feasibility Study* has been prepared for the U.S. Air Force Center for Environmental Excellence (AFCEE) as part of the Air Force Installation Restoration Program under contract number F41624-97-D-8006, Delivery Order 6. This study is part of continuing efforts by the Air Force to address groundwater contamination at the Massachusetts Military Reservation (MMR) on Cape Cod, Massachusetts. A detailed description of groundwater contamination in the FS-28 and FS-29 plumes can be found in the *Final Southwest Operable Unit (SWOU) Remedial Investigation (RI)* (AFCEE 1999c).

The SWOU RI concluded that for remedial consideration, there are six distinct plumes within the SWOU area: the Chemical Spill-4 (CS-4), CS-20, CS-21, FS-13, FS-28, and FS-29 plumes (Figure 1-1). These six plumes were addressed in the Final SWOU Feasibility Study (AFCEE 1999b).

Following the issuance of the draft *Proposed Plan for the Southwest Operable Unit* (AFCEE 1999d), AFCEE, the U.S. Environmental Protection Agency (EPA) and the Massachusetts Department of Environmental Protection (DEP) agreed that the FS-28 and FS-29 plumes should be removed from the final *Proposed Plan for the Southwest Operable Unit* (AFCEE 1999a). It was also agreed that additional alternatives be developed for the FS-28 plume and that the alternatives for the FS-29 plume be further reviewed. Therefore, this document supercedes the previous feasibility study with respect to remedial alternatives for the FS-28 and FS-29 plumes.

As outlined in the National Oil and Hazardous Substances Contingency Plan (40 CFR 300), the objective of this feasibility study is to develop and evaluate appropriate remedial alternatives so an appropriate remedial action can be selected. The remedial investigation/feasibility study (RI/FS) process represents the methodology that the Superfund program (National Contingency Plan, 40 CFR 300.430) has established for characterizing the nature and extent of risks posed by uncontrolled hazardous waste sites and for evaluating potential remedial options (EPA 1988). The goal of the RI/FS process

is to “gather information sufficient to support an informed risk management decision regarding which remedy appears most appropriate for a given site” (EPA 1988). To achieve this goal, the SWOU RI characterized the contamination present at the site, assessed human health and ecological risks, and provided recommendations for remedial action objectives and preliminary remediation goals (AFCEE 1999c). This study reviews findings and recommendations presented in the RI and develops and evaluates specific remedial alternatives. This study is composed of seven sections:

- Section 1.0 Introduction: describes the purpose and contents of this FS. The location, distribution, and types of contamination present are also discussed.
- Section 2.0 Remedial Action Objectives and Potential Response Actions: presents the purpose and goals of remedial action.
- Section 3.0 Remedial Technologies Identification and Screening: identifies technologies capable of achieving the remedial objectives and screens them for applicability to groundwater contamination found within the SWOU. Technologies are evaluated on the basis of effectiveness, implementability, and cost.
- Section 4.0 Development and Evaluation of Alternatives: discusses the criteria for developing, screening and evaluating alternatives. A system for evaluating remedial alternatives in accordance with the National Contingency Plan is presented.
- Section 5.0 FS-28 Plume: discusses alternatives for remediating the FS-28 plume. This section relies heavily on the recently completed *Final Engineering Evaluation, Cost Analysis, and Execution Plan for Coonamessett River FS-28 Bog Separation Project* (AFCEE 1998a) and the *Final FS-28 Non-Time-Critical Action Memorandum* (AFCEE 1999e).
- Section 6.0 FS-29 Plume: discusses remedial alternatives for the FS-29 plume.
- Section 7.0 References: lists the documents referenced throughout this study.

Following issuance of a proposed plan for public comment, a record of decision (ROD) will document the selected alternative. Responses to comments received during the public comment period will be found in a Responsiveness Summary which is part of the ROD. Once the ROD is issued, remedial design (if necessary) will begin. During the remedial design phase, many of the uncertainties and generalities present in the FS will be resolved.

## 1.1 ENVIRONMENTAL CONTAMINATION

The FS-28 and FS-29 plumes are detached from their source areas, which are currently undefined. Searches of the MMR administrative record were conducted under the SWOU RI and previous investigations in order to locate potential source areas. Locations of likely contamination have been investigated based on the findings of these record searches. In most cases, contaminated soils were removed. A summary of the investigation and remediation status of potential source areas for the FS-28 and FS-29 plumes is included in Table 1-1. Given the number of potential source areas on MMR and the distance that these plumes have traveled (based on their present locations), it is not possible to pinpoint source areas for the FS-28 and FS-29 plumes.

**Table 1-1**  
**Investigation and Remediation Status of Potential Source Areas**

Site Name	Records Search	SI	RI	FS	PP	DD	ROD	Notes
FS-2	1983	1989-1990	1991	1991				Supplemental sampling is needed to complete the RI
FS-2 (USCG)		1993				1997		DD – proposed no further action
FS-7	1986	1993, 1996						Soil excavation, asphalt batching FY00
FS-9	1986	1985 & 1993	1998	1998	1998		1999	ROD – asphalt batching, off-site disposal, potential soil vapor extraction FY00
FS-13	1995	1996	1997					RI – data package only
FS-18	1986	1993			1998			Asphalt batching FY00
FS-19	1986	1993	1993, 1998	1996	1998		1999	ROD – proposed confirmation sampling, no further action
FS-26 (USCG)		1996				1997		DD – no further action
FS-27		1993, 1996				1997		DD – proposed no further action
LF-2 (USCG)	1986					1990		DD – no further action

SI = Site Inspection  
PP = Proposed Plan  
FY = fiscal year

RI = Remedial Investigation  
DD = Decision Document

FS = Feasibility Study  
ROD = Record of Decision

The discussion of plume contaminant concentrations and corresponding regulatory standards below references federal maximum contaminant levels (MCLs), except when Massachusetts maximum contaminant levels (MMCLs) are more stringent (DEP 1998). In these cases, the MMCL is specifically cited.

FS-28 Plume. Ethylene dibromide (EDB) is the primary constituent of concern in the FS-28 plume. The plume extends from the Crane Wildlife Management Area, under the western portion of Coonamessett Pond, and terminates in the cranberry bogs surrounding the Coonamessett River. (Geographical features and current land use patterns are shown in Figure 1-2.)

The volumes of groundwater with the highest concentrations of EDB within the plume are being captured by an extraction and treatment system—referred to as the extraction well (EW-1) system (69EW0001)—that has been operational since October 1997. This system was installed to capture most of the plume mass at Hatchville Road and minimize upwelling into the Coonamessett River system. Previous modeling (AFCEE 1998e) indicates that some contamination may be traveling east of the extraction system zone of capture and (without action) could eventually discharge into the surface water. In addition, a small portion of the plume downgradient of the extraction well was discharging into the Coonamessett River and associated cranberry bogs. To minimize the discharge of EDB to these areas, additional extraction capacity, in the form of shallow well-points, was added to the system in April 1999 (Figure 1-3). Since May 1999, EDB has not been detected in the surface water in the bogs. This is believed to be attributable to the effectiveness of the time-critical and non-time-critical removal actions implemented by AFCEE. Additional actions taken by AFCEE in response to the FS-28 plume include the construction and operation of a wellhead treatment system for the town of Falmouth's Coonamessett Water Supply Well and the construction of berms and sheet piles to separate the river from neighboring cranberry bogs.

The highest concentration of EDB in the FS-28 plume – 18 micrograms per liter ( $\mu\text{g/L}$ ) – (Table 1-2) was detected in a monitoring well near the extraction well located south of Hatchville Road; concentrations decrease significantly to the north. The maximum concentration just north of Hatchville Road was 14  $\mu\text{g/L}$ , and the maximum concentration just south of the western arm of Coonamessett Pond was 4.9  $\mu\text{g/L}$  (Figure 1-4). Between the western arm of Coonamessett Pond and Route 151, concentrations continue to decrease to the north. The highest concentration of EDB detected just north

of the western arm of Coonamessett Pond was 3.1 µg/L, and the highest concentration detected between Route 151 and Boxberry Hill Road was 0.025 µg/L. The thickest portion of the plume (approximately 220 feet) occurs downgradient of the extraction well, where discharge to surface waters occurs. The results of recent (April 1999) FS-28 plume sampling and analysis in the northern part of the plume are presented in Appendix D.

**Table 1-2**  
**FS-28 Plume Maximum Contaminant Concentration**

<b>Constituent</b>	<b>Maximum Detected (µg/L)</b>	<b>Location</b>	<b>MCL (µg/L)</b>	<b>MMCL (µg/L)</b>
1,2-dibromoethane (EDB)	18	69MW1304	0.05	0.02

Just south of the western arm of Coonamessett Pond, the FS-28 plume lies from -85 to -220 feet mean sea level (msl), and stays relatively deep until it passes under Hatchville Road. In the area between Coonamessett Pond and Route 151, EDB has been detected generally between the elevations of -30 and -190 feet msl. There is no conclusive evidence to indicate that the FS-28 plume comes in contact with the bottom of Coonamessett Pond, although this is possible. None of the 45 water samples or 10 sediment samples collected from Coonamessett Pond during the RI contained detectable concentrations of EDB. North of Route 151, the FS-28 plume becomes laterally and vertically discontinuous at various elevations ranging from -20 to -220 feet msl. The trailing edge of the FS-28 plume is difficult to define because the concentrations are less than 0.1 µg/L and generally close to the EDB detection limit of 0.004 µg/L. The northern-most detection of EDB associated with the FS-28 plume is located approximately 1000 feet south of the MMR boundary.

FS-29 Plume. The FS-29 plume is over 9000 feet long, extending from the Crane Wildlife Management Area across Route 151. The maximum width of the plume, just south of Route 151, is approximately 1300 feet. EDB and carbon tetrachloride (CCl<sub>4</sub>) generally appear together in this plume, although not in every sample. The plume is comprised of two lobes, the shallower one occurring from approximately -30 to -100 feet msl, with an average thickness of 30 feet, and the deeper one occurring from



approximately -120 to -220 feet msl, with a thickness ranging from 30 to 50 feet (Figure 1-5).

The plume is defined by the presence of EDB and/or  $\text{CCl}_4$  at concentrations above MCLs/MMCLs, although at two locations (69MW1516 and 69MW1522), the plume appears to intersect the CS-21 plume. At 69MW1516, tetrachloroethene (PCE) was detected in four samples, although all detected PCE concentrations were well below the reporting limit of 1  $\mu\text{g/L}$ .

The maximum EDB concentration detected in a borewater sample was 0.108  $\mu\text{g/L}$ , and the maximum EDB concentration detected in a monitoring well sample was 0.071  $\mu\text{g/L}$  (Table 1-3). Both samples were from monitoring well 69MW1536, located in the upper lobe downgradient of Route 151. The maximum  $\text{CCl}_4$  concentration was 9.5  $\mu\text{g/L}$ , at 69MW1543, which is located in the deeper lobe downgradient of Route 151.

**Table 1-3**  
**FS-29 Plume Maximum Contaminant Concentrations**

Constituent	Maximum Detected ( $\mu\text{g/L}$ )	Location	MCL ( $\mu\text{g/L}$ )	MMCL ( $\mu\text{g/L}$ )
1,2-dibromoethane (EDB)	0.071	69MW1536	0.05	0.02
carbon tetrachloride ( $\text{CCl}_4$ )	9.5	69MW1543	5	5

The data presented represents the highest concentrations detected in a monitoring well sample. A bore water sample collected from 69MW1536 contained 0.108  $\mu\text{g/L}$  of EDB.

## 1.2 PHYSICAL DISTRIBUTION OF CONTAMINATED WATER

A key factor in determining the feasibility and cost of various remedial groundwater treatment options is the depth of the contamination relative to the ground surface. Contamination in the body of the FS-28 plume and all of the FS-29 plume is deep below the ground surface (Table 1-4). The distal portion of the FS-28 plume rises to its discharge point in the Coonamessett River.

**Table 1-4  
Approximate Plume Depths**

Plume	Average Depth (Feet bgs)	Depth Range (Feet bgs)
FS-28	150	0 to 270
FS-29	Upper Section 110 Lower Section 210	80 to 140 160 to 270

bgs – below ground surface

### 1.3 CONTAMINANT MASS AND VOLUMES OF CONTAMINATED GROUNDWATER

The FS-28 and FS-29 plumes are defined as areas of groundwater contaminated by one or more organic compounds exceeding drinking water standards, where the contaminants are distributed in a laterally and vertically continuous manner (defined by multiple samples from multiple locations). Based on this definition, estimates of contaminant mass of EDB present and the volume of groundwater exceeding the MMCL for EDB were calculated (Table 1-5).

**Table 1-5  
Estimated EDB Mass and Volumes of Contaminated Groundwater**

Plume	Constituent	Mass [kg]	Volume [million ft <sup>3</sup> ]	Volume [billion gallons]	Average Concentration [µg/L]**
FS-28	EDB	11.7	583	4.36	0.71
FS-29*	EDB	0.160	155	1.16	0.040

kg = kilograms

ft<sup>3</sup> = cubic feet

µg/L = micrograms per liter

\*Carbon tetrachloride has not been included in this table because of its limited extent.

\*\* Average concentration has been estimated by dividing mass (in micrograms) by volume (in liters).

### 1.4 RISK ASSESSMENT SUMMARY

This section summarizes the risk to human health and the environment attributable to contaminants of concern in the FS-28 and FS-29 plumes. Based on the risk assessment presented in the SWOU RI (AFCEE 1999c), the groundwater contaminants of concern are EDB for the FS-28 plume and EDB and CCl<sub>4</sub> for the FS-29 plume.

Current and future land use was taken into consideration in the risk assessment. For example, since the FS-28 plume is upwelling into the cranberry bogs surrounding the Coonamessett River, the risk to adult waders, child waders, cranberry workers, and humans ingesting fish caught in the river were evaluated based on contaminant

concentrations in the surface water and sediment. Land use was also considered for exposure to groundwater. For example, since there are no current residents in the Crane Wildlife Management Area, which overlies the trailing edges of both the FS-28 and FS-29 plumes, the groundwater contamination in that area does not pose a current risk. Similarly, in the residential neighborhoods located south of the Crane Wildlife Management Area, residents in homes that overlie both plumes are not currently threatened because they are connected to the municipal water supply. However, because the future land use for the areas surrounding these plumes is uncertain, the risk assessment conclusions focus on the future groundwater use scenarios, which conservatively assume that the residents would be exposed to the highest detected concentrations of all contaminants of concern over the course of their lifetime.

The cancer risks and noncancer hazards for adult and child swimmers and fish consumers exposed to Coonamessett Pond were all less than the regulatory criteria. Noncancer hazards for exposure to the Coonamessett River were also less than the regulatory threshold of a hazard index (HI) of one. However, cranberry workers (with the reasonable maximum exposure) who are exposed to the Coonamessett River may have cancer risks within the EPA risk management criteria range ( $1 \times 10^{-6}$  to  $1 \times 10^{-4}$ ) and less than the DEP criteria ( $1 \times 10^{-5}$ ). The primary contributor to this risk is EDB in river water. Adult and child waders in the Coonamessett River may have cancer risks within the EPA risk management criteria range but slightly higher than the DEP criteria. This risk is primarily due to EDB in river water and arsenic in sediment. The Coonamessett River fish consumer (with the reasonable maximum exposure) may have cancer risks higher than both regulatory criteria primarily due to EDB and arsenic in the river water.<sup>1</sup>

There are many conservative factors built into the human health risk assessment. The exposure scenarios and health-protective exposure factors used generally overestimate rather than underestimate exposure. For each risk area (plume, pond, or river system),

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<sup>1</sup> The baseline risk assessment was based on data collected in 1998. Since May 1999, EDB has not been detected in the surface water in the bogs. This is believed to be attributable to the effectiveness of the time-critical and non-time-critical removal actions implemented by AFCEE in the past three years.

the assessment assumed that an individual receptor would be exposed to all contaminants at their respective maximum concentrations detected within a given area. Therefore, the conclusions are conservative because the nature and extent of groundwater, surface water and sediment contamination within each risk area vary widely with vertical and lateral location. Regarding the consumer of fish caught in the Coonamessett River, there is some uncertainty associated with the estimated factor representing the bioaccumulation of EDB in fish tissue.

It is assumed human exposure remains constant over the lifetime of an individual. In fact, lifestyle changes and movement of individuals in and out of the potentially exposed community also affect exposure duration. Adult exposure durations are assumed to last from two to three decades at the current groundwater, surface water, and/or sediment contaminant concentrations without any decrease in concentrations. Chronic reference concentrations and doses were used for all exposure scenarios even though some exposure pathways were 6.6 years or less. Slope factors developed by the EPA are generally conservative and represent the upper bound limit of the probability of a cancer response. Also, it is possible for carcinogenic risk to be reported for chemicals that may not induce carcinogenesis.

Other factors introduce a less biased uncertainty to the risk assessment. Reference concentrations and doses developed by the EPA are generally considered to have uncertainty spanning an order of magnitude or more. There are numerous uncertainties concerning the adjustment of oral reference doses and slope factors to dermal reference doses and slope factors based on intestinal absorption. Finally, carcinogenic risks and noncancer hazards for different contaminants were totaled; this ignores the possible synergistic or antagonistic effects between different contaminants.

The ecological risk assessment presented in the SWOU RI consisted of a screening level and a baseline risk analysis conducted for surface water and sediment in the Coonamessett River and Coonamessett Pond, which surround the FS-28 plume. The risk analysis indicates that there could be ecologically significant adverse effects for individual alewife and eastern box turtle in the Coonamessett River and for individual

alewife, mucket, osprey, and heron in the pond. These risks are primarily due to cobalt and mercury in the pond environments and arsenic, cadmium, mercury, iron, zinc, lead, pyrene, and fluoranthene in the river environment. However, if the effects of non-MMR related metals were eliminated, there would be no significant adverse effects on SWOU ecological receptors.

The SWOU area conceptual model indicates that the only existing pathway for MMR-related contaminants to reach surface water is through the discharge of groundwater to surface water bodies. Therefore, only contaminants of potential concern (COPCs) that are mobile in groundwater and present in upgradient groundwater at elevated concentrations can be considered MMR-related. EDB-contaminated groundwater is known to discharge into the Coonamessett River, but there is no indication that the same relationship exists for metals, which are not considered MMR-related contaminants. Therefore, since MMR-related organic contaminants are not driving the ecological risk, and the risk is primarily attributable to natural levels of metals in emerging groundwater, surface water, and sediment, human health risk is the primary driver for future remedial action.

Contaminants for which the future reasonable maximum exposure would result in an excess lifetime cancer risk greater than one in a million or a hazard index greater than one were determined for the FS-28 and FS-29 plumes. In the baseline risk assessment, all detected compounds were initially considered for use in the quantification of risk. However, certain contaminants were eliminated from consideration as contaminants of concern for these plumes if they met any of the following criteria:

- Contaminant is present at similar concentrations in background samples or has fate and transport properties which preclude migration from MMR.
- Contaminant is present at similar concentrations in lab blanks or equipment blanks, or it is otherwise attributable to sampling or analytical contamination.
- Contaminant concentrations are so low that no risk-based reference concentrations were exceeded by the maximum concentration.
- Contaminant was not detected in the plumes of concern.

- The detection frequency is below criteria for retention as a contaminant of potential concern.
- Contaminant has sporadic distribution and is not present in multiple samples from similar area, so no contiguous area of groundwater contamination can be defined.

The risk assessment in the SWOU RI (AFCEE 1999c) did not evaluate groundwater risks on a plume-by-plume basis. Instead, the entire study area was broken into four risk areas, based primarily on land use. To make the transition from the RI's risk area approach to a plume-by-plume approach, each contaminant of potential concern from the risk areas surrounding the FS-28 and FS-29 plumes was screened according to spatial distribution and its measured concentrations within the plumes. The results of this screening are presented in Table 1-6. Based on this analysis, only CCl<sub>4</sub>, EDB, and PCE were retained as contaminants of concern for these two plumes. Table 1-7 presents the contaminant-specific contributions to the total (RME) risk (to future residents) values for the two plumes.

**Table 1-6  
Screening Contaminants of Concern for the FS-28 and FS-29 Plumes**

Contaminant of Potential Concern	10-REC (µg/L)	HI-1 HEC (µg/L)	Max. detect (µg/L)*	COC (Y/N)	Reason for selection or rejection
Arsenic	0.057	11	11	N	The highest detections (11.1 µg/L at 38MW0009, 7.5 µg/L at 32MW1307, and 4.6 µg/L 69MW1519) were more than a mile away from any other detections. The remaining 6 samples had concentrations less than EPA threshold for remedial action (10-4) REC of 5.7 µg/L. Distributions are irregular, and not particular to any VOC or EDB plume(s). There may be a weak relationship between detections ranging from 2.2 to 4.2 µg/L at 69MW1417, 69MW1420, and 69MW1512. There also may be a weak relationship between detections ranging from 2.2 to 3 at 03MW0038, 69MW1515, and 69MW1528. All other samples were nondetects. Generally, arsenic is not attributable to MMR. Reporting limit for arsenic is 5 µg/L, below which results are estimated.
Barium		2500	252	N	Maximum detection is less than HEC.
BEHP	2.3	274	2100	N	Contaminant is artifact of sampling equipment and possibly laboratory contamination.
Cadmium		18	5.2	N	Maximum detection is less than HEC.
CCl <sub>4</sub>	0.24	4.6	32	Y	Carbon tetrachloride is a COC in the FS-29 plume. The highest concentration of CCl <sub>4</sub> in the FS-29 plume is 9.5 µg/L.
Chloroform	0.28	0.90	7.6	N	Contaminant is not attributable to MMR. Chloroform is primarily due to the infiltration of chlorinated water.
Chromium		77	151	N	Only two samples (151 µg/L from 69MW1290B and 83 µg/L from 69MW1283B) exceeded HEC. Distribution appears random and not particular to any VOC or EDB plume(s). Chromium is generally not attributable to MMR.
EDB	0.00095	0.60	18	Y	EDB is a COC in the FS-28 and FS-29 plumes. The highest concentration in the FS-28 plume is 18 µg/L, and the highest concentration of EDB in the FS-29 plume is 0.071 µg/L.
Manganese		840	1820	N	Only four wells contained manganese concentrations above the HEC. The distribution of manganese in the SWOU appears random and is considered not to be attributable to MMR.
Nickel		733	110	N	Maximum detection is less than HEC.
1,1,2,2-TCA	0.088		22	N	Contaminant is not found in either the FS-28 or FS-29 plumes. Its distribution is limited to the CS-4 plume.
PCE	0.11	242	140	N	PCE is a risk-driver in the FS-28 and FS-29 plumes. The highest concentration in the FS-28 plume is 2.4 µg/L, and the highest concentration of PCE in the FS-29 plume is 0.471 µg/L. However, because PCE concentrations in these plumes are less than the MCLs and the water containing the low levels of PCE is contaminated by higher levels of EDB, CCl <sub>4</sub> , or both, PCE is not considered a COC.
TCE	2.45		710	N	TCE is not a COC in the FS-28 or FS-29 plumes because the concentrations were less than the REC.
Thallium		2.9	9.7	N	Distribution of thallium within SWOU is random and not particular to any VOC or EDB plume(s). Generally, thallium is not attributable to MMR.

BEHP = bis (2-ethylhexyl) phthalate

CCl<sub>4</sub> = carbon tetrachloride

COC = contaminant of concern

EDB = ethylene dibromide

HEC = hazard equivalent concentration

HI = hazard index

1,1,2,2-TCA = 1,1,2,2-tetrachloroethane

\* = Contaminants of potential concern were identified in the risk assessment as being associated with SWOU groundwater south of the MMR boundary.

\*\* = The concentrations shown are the highest detections in the SWOU groundwater south of the MMR boundary, which may not be the highest concentrations within the FS-28 or FS-29 plumes.

PCE = tetrachloroethene

REC = risk equivalent concentration

TCE = trichloroethene

VOC = volatile organic compound

µg/L = micrograms per liter

Bold = the lower of the pair of equivalent concentrations (RECs and HECs).

**Table 1-7**  
**Plume-Specific Risk Values**  
**Based on Reasonable Maximum Exposure for Future Residents**

<b>Contaminant of Potential Concern</b>	<b>10<sup>-6</sup> REC (µg/L)</b>	<b>FS-28 Maximum Concentration (µg/L)</b>	<b>FS-28 Plume Risk</b>	<b>FS-29 Maximum Concentration (µg/L)</b>	<b>FS-29 Plume Risk</b>
carbon tetrachloride (CCl <sub>4</sub> )	0.24	NA	NA	9.5	4.0 X 10 <sup>-5</sup>
1,2-dibromoethane (EDB)	0.00095	18	1.9 X 10 <sup>-2</sup>	0.071	7.5 X 10 <sup>-5</sup>
tetrachloroethene (PCE)	0.11	2.4	2.2 X 10 <sup>-5</sup>	0.47 J	4.3 X 10 <sup>-6</sup>
<b>TOTAL PLUME RISK</b>			<b>1.9 X 10<sup>-2</sup></b>		<b>1.2 X 10<sup>-4</sup></b>

J = estimated value

REC = risk equivalent concentration

NA = not applicable



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## 2.0 REMEDIAL ACTION OBJECTIVES AND POTENTIAL RESPONSE ACTIONS

The SWOU RI (AFCEE 1999c) recommended separate remedial action objectives for each of four separate study areas within the SWOU. The discussion below focuses those objectives on the FS-28 and FS-29 plumes. Remedial action objectives and potential response actions are presented for each plume.

### 2.1 FS-28 PLUME

#### Remedial Action Objectives to Protect Human Health:

- Prevent or reduce residential exposure to EDB exceeding 0.02 µg/L in groundwater.
- Restore the aquifer to its beneficial uses within a reasonable time.
- Prevent worker contact and child and adult wader contact with Coonamessett River water containing unacceptable concentrations of EDB.
- Prevent or reduce ingestion to fish exposed to Coonamessett River water containing unacceptable concentrations of EDB.

Actions Taken to Date: Several actions have already been taken in response to the FS-28 plume. These include:

- Connections to municipal water supplies have been provided for all private well users above and in the immediate vicinity of the plume.
- A granular-activated carbon system has been installed at the Coonamessett Water Supply Well to protect this public water supply.
- An extraction well (EW-1) and treatment system have been constructed and operated to remove the highest concentrations of EDB from the plume.
- The treatment system has been modified to add extraction from shallow well-points to prevent contaminated water from entering the Coonamessett River.
- Systems have been put into place to provide agricultural users with clean water.
- Berms and sheet piles have been installed to separate the Coonamessett River from the surrounding cranberry bogs.

These actions should be considered in relation to the remedial action objectives. The municipal water supply hookups and the treatment system for the Coonamessett

Water Supply Well prevent residential exposure to plume contaminants. Operating in concert, EW-1 and the shallow well-points capture plume contaminants before they discharge to the river in detectable concentrations. Since May 1999, no EDB has been detected in the Coonamessett River. This directly addresses the remedial action objectives which call for prevention of worker and wader contact to unacceptable concentrations of EDB in the river and prevention or reduction of the ingestion of fish exposed to unacceptable concentrations of EDB.

Additional alternatives are being considered that provide quicker aquifer restoration.

#### Potential Response Actions:

- Use no remedial action with long-term monitoring.
- Continue operation of the EW-1 extraction, treatment, and discharge system, including continued operation and maintenance of the wellhead protection system for the Falmouth Coonamessett Water Supply Well (CWSW) (Figure 1-3). Operation of the shallow well-points would be discontinued under this alternative.
- Modify the existing extraction, treatment and discharge system to include additional capture in the bogs south of EW-1 in order to reduce EDB concentrations in the river system to acceptable concentrations<sup>2</sup>. Provide an alternate supply of water for cranberry bog operations. Use berms to prevent EDB-contaminated water from contacting productive bogs.
- Construct an extraction, treatment, and reinjection (ETR) system upgradient of existing extraction locations in order to reduce the time it will take the aquifer to be restored. Pursue other actions described in the third bullet above.

## **2.2 FS-29 PLUME**

#### Remedial Action Objectives to Protect Human Health:

- Prevent or reduce residential exposure to EDB exceeding 0.02 µg/L and CCl<sub>4</sub> exceeding 5 µg/L in groundwater.
- Restore the aquifer to its beneficial uses within a reasonable time.

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<sup>2</sup> This modification has been completed. The remainder of the Feasibility Study will discuss this potential response action as currently operational.

Potential Response Actions:

- Use no remedial action with long-term monitoring.
- Prevent or reduce future residential exposure to FS-29 plume contaminants through institutional and engineering controls.
- Construct a groundwater ETR system to hydraulically control and capture 100 percent of plume contaminants.
- Construct a groundwater ETR system to reduce plume mass (the objective would be less than 100-percent plume capture).
- Construct a groundwater ETR system to expedite remediation of the central portion of the plume (the objective would be less than 100-percent plume capture).
- Use recirculating wells to reduce contaminant concentrations.

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### 3.0 REMEDIAL TECHNOLOGIES IDENTIFICATION AND SCREENING

Potentially applicable remedial technologies were identified based on previous experience in treating groundwater contamination at MMR, professional judgment, EPA databases (EPA 1992, 1998a) and input from regulatory agencies and the Environmental Technology Center on the MMR. A wide range of technologies was identified and evaluated for effectiveness, implementability and cost (Figure 3-1).

Effectiveness. This criterion evaluates each technology based on its:

- proven ability to achieve cleanup goals,
- potential impacts on human health and the environment, and
- reliability with respect to site contaminants.

Innovative technologies that have not been proven in full-scale operations but offer potentially substantial advantages in other areas (e.g., simplified operations) have been considered for alternative development.

Implementability. This criterion evaluates the technical and administrative feasibility of implementing the technology at the site.

Cost. This criterion evaluates whether the capital and operating costs of implementing the technology are low, moderate or high. The standard for this comparison used in this document is an ETR system using granular-activated carbon (GAC) adsorption, vertical extraction wells and reinjection wells. This standard was chosen because of the availability of detailed cost data.

On the basis of this evaluation, technologies were screened. Those that are best suited to achieving the remedial action objectives were then combined to form remedial action alternatives. These alternatives are presented for the FS-28 and FS-29 plumes in Sections 5.0 and 6.0, respectively. Any technology that is ineffective in treating the contaminants of concern or is not technically feasible for implementation in the SWOU has not been considered further in the development of alternatives.

This section addresses the technologies under consideration in three groups: in situ technologies, ETR technologies, and recirculating wells.

### **3.1 IN SITU TECHNOLOGIES**

Although ETR technologies have been used for many groundwater remediation activities, they have several disadvantages. These include high installation and annual operating costs, relatively large aboveground facilities, well and pipeline fouling, and the need for extensive monitoring. Long treatment times for ETR systems, often on the order of decades, also result in high life cycle costs. To avoid these difficulties, a variety of in situ treatment technologies has been developed. The main advantage of in situ treatment is that it allows groundwater to be treated without being brought to the surface, resulting in potentially significant cost savings (FRTR 1997). Four of these technologies have been considered below: reactive walls, air sparging, in situ biological treatment systems, and monitored natural attenuation.

#### **3.1.1 Reactive Walls**

Reactive walls are permeable barriers installed underground to treat contaminated groundwater. Reactive walls, also known as passive treatment walls, are generally constructed inside a large trench perpendicular to the flow path of contaminated groundwater. Typically they are filled with materials selected for their ability to remediate specific types of contaminants (EPA 1996). Impermeable sheet piles and slurry walls may be used to funnel a plume through permeable treatment sections (Figure 3-2). This variant of a reactive wall is referred to as a funnel and gate system.

Two types of reactive walls—sorption and degradation barriers—could be used in treating the types of contaminants present in the FS-28 and FS-29 plumes. Sorption barriers contain materials that remove contaminants from the groundwater flow by physical attraction (surface phenomena), chemical adsorption, or electrostatic attraction (Gossett 1996). Contaminants are fixed but not destroyed. Sorption barriers are typically filled with such materials as zeolites or activated carbon. Degradation barriers degrade contaminants as contaminants pass through the wall.

Such walls may be filled with zero valent iron or nickel-plated iron which are capable of abiotically degrading volatile organic compounds (VOCs), (Hocking and Wells 1997) and EDB (Rajagopal and Burris, in press). Degradation barriers may also contain a mixture of nutrient and oxygen sources to promote biodegradation.

Because cost and safety considerations increase exponentially with depth, installation of reactive walls is only technically feasible to a depth of approximately 13-20 feet below ground surface (bgs) in sandy soils when standard trenching techniques are used. The distal portion of the FS-28 plume is the only area where contaminants are shallow enough to consider installing reactive walls using standard trenching techniques. However, anticipated construction and access difficulties associated with working in an active cranberry bog make this technology inappropriate for this location.

In addition to standard trenching technologies, it is possible to install a treatment wall using hydraulic fracturing techniques. At the MMR, a reactive wall was constructed using hydraulic fracturing techniques and zero valent iron immediately downgradient of the primary CS-10 source area to degrade PCE contamination. Hydraulic fracturing allowed for the installation of two walls (50 feet long, 40 feet in depth, 3-4 inches thick) from 85 to 125 feet bgs. Installation costs for a reactive wall using hydraulic fracturing are high. However, it is anticipated that operations and maintenance costs of this technology will be considerably lower than those of an ETR system using carbon adsorption. The CS-10 wall is currently the deepest permeable treatment wall in existence. Walls for the SWOU plumes would need to be still deeper and many times longer. Because of anticipated difficulties with installing a permeable treatment wall at the required depth and because of high installation costs, reactive wall technology is not considered further.

### **3.1.2 Air Sparging**

Air sparging removes volatile chemicals from groundwater by bubbling contaminant-free air through the subsurface saturated zone to transfer contamination from the



aqueous to the vapor phase. Air sparging is often used in combination with soil vapor extraction.

When feasible, air sparging is generally less expensive than ETR technology. Air sparging can effectively treat contaminants that readily partition from the aqueous to the vapor phase and that are located in a permeable subsurface lithology (EPA 1998b). EDB, present in both the FS-28 and FS-29 plumes, is not sufficiently volatile to be removed with air sparging. Therefore, this technology will not be evaluated further. (See Subsection 3.2.3.2 for a discussion on the effectiveness of air stripping on contaminants of potential concern and Table 3-1 for a listing of Henry's Law constants.)

### **3.1.3 In Situ Biological Treatment Systems**

Biodegradation naturally degrades many groundwater contaminants, but this process is often too slow to prevent contaminant migration. Bioremediation techniques stimulate the growth of microorganisms that consume contaminants to enhance naturally occurring biodegradation processes. When conducted in situ, this is generally accomplished by adding nutrients and electron donors, and by controlling dissolved oxygen and pH. Microorganisms adapted to the destruction of specific contaminants may be applied to enhance the process.

EDB is resistant to aerobic degradation. (The groundwater in the FS-28 and FS-29 plumes is generally aerobic.) It appears to be degradable under anaerobic conditions with a half-life of 19.6 days (Howard et al. 1991). In the natural environment, the degradation of a compound may lower the concentration of that compound to a threshold concentration, below which biodegradation will not occur. At concentrations less than the threshold level, organisms which are otherwise capable of degrading a compound cannot receive sufficient energy from that degradation reaction to continue to function. The MMCL for EDB is 0.02 µg/L, and it is quite possible that this standard is less than the threshold concentration needed for degradation to continue to take place. Within the SWOU it would be necessary to

create an anaerobic zone to degrade EDB, followed by an aerobic zone to restore the aquifer.

Anaerobic conditions can be created through the addition of electron donors such as methane, hydrogen sulfide, lactic acid or hydrogen. Naturally occurring bacteria will use dissolved oxygen in the process of consuming the electron donor. Once the available oxygen has been consumed, other species of bacteria capable of using other electron acceptors will begin to dominate. Included are species that can dehalogenate EDB. Compared to aerobic degradation, anaerobic degradation generally involves additional intermediary steps, and the number of species capable of anaerobic biodegradation are fewer. This results in anaerobic environments being less robust and producing more recalcitrant byproducts. Although anaerobic in situ bioremediation has been used at numerous sites (EPA 1998a), a review of EPA databases revealed no site at which an anaerobic aquifer was created from an aerobic aquifer for the purpose of contaminant destruction (EPA 1992, 1998a).

Hydrogen Injection. One variant of in situ anaerobic biodegradation is hydrogen injection. When hydrogen is initially added to an aerobic aquifer, it acts as an electron donor and removes oxygen, nitrate, and other electron acceptors, creating anaerobic conditions. Once an anaerobic environment has been established, bacteria capable of reductive dehalogenation can gain a competitive advantage. Such bacteria can use hydrogen as an electron donor to remove bromine from EDB. Vendors of this technology claim that hydrogen injection is a superior alternative because it eliminates the potentially rate-limiting fermentation step present with the injection of methane and similar reagents that are required to establish anaerobic conditions (Newell et al. Undated).

Once anaerobic degradation processes were established (and demonstrated through monitoring), oxygen addition would be needed downgradient of the anaerobic treatment zone to restore the aquifer and fix inorganics that may have become soluble under anaerobic, low oxidation reduction potential (ORP) conditions. Aerobic conditions may be reestablished through forced air injection, oxygen injection, air

stripping in recirculating wells, or through the addition of hydrogen peroxide. Only limited concentrations of hydrogen peroxide can be applied because of its toxicity to microorganisms (Fetter 1993).

In both aerobic and anaerobic systems, it may be desirable to add nutrients and control pH. Phosphorous and nitrogen are the nutrients most likely to be deficient in the aquifer, but small amounts of other nutrients and minerals may also be required. Nutrients must be added in their bioavailable state (for instance, ammonia for nitrogen and phosphate for phosphorus). However, the addition of phosphates may cause soil plugging due to precipitation reactions with cations such as iron and calcium (FRTR 1997).

Although there is a wide variety of bacterial species naturally present in the aquifer, it may be desirable to augment these populations. Cultures of indigenous bacteria may be collected, separately cultured, and returned to the site to rapidly increase the microorganism population at the site. During this process an attempt may be made to partially isolate and encourage the growth of species that preferentially consume contaminants present at the site. Because most species of bacteria present in the aquifer tend to remain fixed to the soil matrix, bacterial culturing may be used to encourage species that move freely with the groundwater. U.S. Air Force research has found no evidence that the introduction of non-native microorganism populations is beneficial to remediation efforts in the situations tested (FRTR 1997).

In summary, to remediate EDB using in situ biotechnology in portions of the SWOU aquifer, it would be necessary to turn these areas into anaerobic zones. Doing this to large sections of the aquifer would involve the injection of correspondingly large amounts of nutrients and electron donors. Due to the low levels of contamination present, most of the electron donor addition would be used to remove oxygen from the aquifer and not for reductive dehalogenation. Creating large anaerobic zones would have substantial impact on the subsurface environment and greatly alter local geochemical balances. Metals released in these zones would form a potential risk to human health and the environment. Full scale applications of biological treatment

systems, although generally less expensive than ETR systems, have experienced numerous operational difficulties, such as aquifer fouling. Thus, based on the effectiveness criteria outlined in Section 3.0, in situ biological treatment is not considered further as a remedial alternative for the FS-28 and FS-29 plumes.

#### **3.1.4 Monitored Natural Attenuation**

Monitored natural attenuation (MNA) can be defined as the use of naturally occurring contaminant degradation and dispersion processes to remediate contaminated groundwater; MNA must be demonstrated with environmental monitoring. Although MNA is not an active remedial technology, remedial alternatives based on MNA could be employed for the FS-28 and FS-29 plumes. The EPA (1997) defines MNA as “the reliance on natural attenuation processes to achieve site-specific remedial objectives within a time frame that is reasonable compared to that offered by more active methods.”

The natural processes that can affect the transport of organic contaminants and plume fate in all hydrologic systems include: biodegradation, advection, dispersion, dilution, sorption and desorption, volatilization and abiotic degradation processes, including hydrolysis. A discussion of how these processes affect contaminants in the SWOU is presented in the *SWOU RI* (AFCEE 1999c). The following discussion of natural processes is intended to supplement that discussion with a focus on how the plumes can be expected to change in the future.

Biodegradation of the chlorinated solvents and EDB is not expected to occur at a significant rate. According to Wiedermeier et al. (1996), in areas of low concentrations of native or anthropogenic carbon, and dissolved oxygen concentrations greater than 1.0 milligrams per liter (mg/L), reductive dechlorination will not occur. Howard et al. (1991) suggest an aerobic degradation half-life for EDB of four weeks to six months in surface water and an anaerobic degradation half-life of 19.6 to 120 days in groundwater. However, EDB will not undergo significant biodegradation in the aerobic groundwater present in the SWOU.

However, hydrolysis could cause a significant decrease in the mass of EDB present in the groundwater. (EDB hydrolysis is as a chemical reaction that can take place in water in which the nucleophilic substitution of a bromine ion ( $\text{Br}^-$ ) with a hydroxyl group ( $\text{OH}^-$ ) yields a less toxic substance.) The rate of hydrolysis is generally measured in terms of a half life. A half-life is the time required for a phenomena to reduce contaminant mass by 50 percent. Howard et al. (1991) suggest that EDB may undergo abiotic degradation by hydrolysis that results in a half-life of 2.2 years (at  $25^\circ\text{C}$ ). Pankow and Cherry (1996) cite a half-life of 2.5 years for EDB (at  $25^\circ\text{C}$ ). Correcting for lower groundwater temperatures in the Upper Cape aquifer ( $12^\circ\text{C}$ , the average of 335 SWOU groundwater samples), this would result in an effective EDB half-life of 5.4 to 7.2 years. (The reader is cautioned to treat all half-life data as approximate.)

With the exception of the distal end of the FS-28 plume, SWOU contamination is not in contact with the water table and will not be subject to an appreciable rate of volatilization. Contamination throughout the SWOU is in the aqueous phase, and the plumes are no longer attached to their source areas. This indicates that sorption and desorption phenomena will not have a significant effect on SWOU plumes.

MNA is less expensive than active treatment systems. An extensive body of knowledge has developed regarding the degradation of chlorinated ethenes (such as tetrachloroethene, trichloroethene [TCE], dichloroethene, and vinyl chloride) in groundwater because of the frequency with which this type of contamination is found. Although EDB contamination may also be a problem of similar magnitude nationwide, concern about EDB contamination began much later. As such, less is known about EDB degradation kinetics in groundwater.

In addition, EDB degradation will be much more difficult to demonstrate than degradation of chlorinated ethenes. For instance, the presence of cis-dichloroethene co-located with TCE is generally considered to be strong evidence that anaerobic degradation of TCE occurred at some point or is still occurring. Similarly, the presence of vinyl bromide could be considered as evidence of the hydrolysis of EDB.

However, at the EDB concentrations of concern within the FS-29 plume, the concentrations of vinyl bromide that could be reasonably expected are well below the detection limit.<sup>3</sup>

Another possible method for demonstrating the degradation of a compound is to show decreasing concentrations over time. Decreasing concentrations may be a result of either degradation or dispersion or both degradation and dispersion. Assuming that EDB actually degrades with a half-life of 7.2 years, if a round of sampling was to be conducted three years after the initial data were collected, the average EDB concentration within the plume would have decreased by 25 percent. However, variability in the individual samples as groundwater moves could also cause the observed average EDB concentration to increase. Given the dynamics of the plume and the statistical uncertainty of the data, even if hydrolysis is acting at the rates discussed, it will be very difficult to demonstrate.

Because of these difficulties in demonstrating the rate of EDB hydrolysis under local groundwater conditions, MNA will not be considered during the development of remedial alternatives.

### **3.2 EXTRACTION, TREATMENT AND REINJECTION TECHNOLOGIES**

ETR technologies have an extensive history of being used to contain groundwater contamination plumes, particularly in highly permeable aquifers such as that of the SWOU study area. However, even a properly designed ETR system may require a long time, on the order of decades, to restore a contaminated aquifer. Construction and annual operating costs for ETR systems are moderately high compared to in situ treatment technologies. By changing pumping rates (and if necessary adding wells), ETR systems provide more flexibility than in situ and recirculating well technologies in dealing with changing site conditions.

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<sup>3</sup> A method detection limit study was conducted in December, 1996 by Quanterra Environmental Services in Tampa, Florida for vinyl bromide by EPA method OLC02.1. The MDL study showed that vinyl bromide could be

The discussion below evaluates technologies for removing contaminated water from an aquifer, treating that water and discharging the treated water. Pretreatment options are also discussed.

### **3.2.1 Extraction Technologies**

Extraction technologies bring groundwater to the surface where it can be treated to remove contamination. Potentially applicable technologies include drains, vertical extraction wells and horizontal extraction wells.

#### **3.2.1.1 Drains**

Drains or collector trenches are horizontal structures designed to collect water. Unlike horizontal extraction wells, drains are installed in a trench, which limits the potential installation depth to approximately 13 - 20 feet (ORD-EPA Undated). They are most effective in capturing water where shallow plumes are migrating in medium to low permeability soils (ANG 1992). In high permeability soils, it is difficult to maintain uniform capture along the length of the drain. Both the FS-28 and FS-29 plumes are generally deep (Table 1-4) and flow primarily through highly permeable sands. For a shallow plume, such as the distal portion of FS-28, drain installation is cost-effective. However, it is believed that any additional capture of this plume would need to be further upgradient and deeper than drains would allow. The other plumes in the SWOU study area are too deep for drain installation to be feasible.

#### **3.2.1.2 Vertical Extraction Wells**

Vertical extraction wells are constructed by drilling a vertical borehole to a selected depth and installing a well with a slotted screen across the contaminated zone. The diameter of the well can vary and is determined from the desired pumping rate, the pumping equipment necessary to achieve this rate, and the anticipated drawdown.

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detected by this method at 0.1 µg/L if the gas chromatograph/mass spectrophotometer (GC/MS) instrument was calibrated for the compound.

Extraction wells with diameters as large as 8 inches have been installed at the MMR. Generally the pump is located within the well, inside or above the well screen.

Vertical extraction wells are somewhat prone to fouling, depending on aquifer geochemistry. They have been used extensively at MMR, and fouling problems have been manageable. Vertical extraction well technology could be easily implemented and is cost effective. Because this is an accepted technology, vertical extraction wells will be considered in the design of treatment systems for the SWOU study area.

### **3.2.1.3 Horizontal Extraction Wells**

The use of horizontal extraction wells installed with horizontal or directional drilling techniques allows for wells that are geometrically aligned with contamination locations and trajectories. Such alignment can minimize the number of wells that need to be installed.

The initial step in directional drilling is to advance a pilot hole along a predetermined path using a jet bit or down-hole motor (Branson 1995) (Figure 3-3). Drilling is assisted by a drilling fluid to maintain the integrity of the bore hole during drilling and screen installation. A down-hole steering system sends bit location information to the surface where adjustments can be made. Although it is possible to construct a well with only an entrance hole (a blind wellbore), it is more economical to use an exit hole (a continuous wellbore) (Wilson Undated). After the pilot hole is complete, a reamer is pulled back through the exit hole to enlarge the bore diameter. The well materials are then pulled into place from the exit hole to the entrance hole. The well can then be developed. Drilling fluids can be removed by acid dissolution, oxidation, or bacterial action followed by sterilization with sodium hypochlorite (Wilson Undated).

Horizontal drilling was developed to install utility lines under existing structures. For environmental restoration, it allows for well installation beneath leaky tanks, landfills and rivers. Such obstacles are not a major concern in remediating the FS-28 and



FS-29 plumes. Beyond a depth of about 20 feet, larger drilling equipment would be required and costs would increase exponentially with depth. At the depths of concern in the SWOU (Table 1-4), horizontal extraction wells are not a feasible alternative at this time.

### **3.2.2 Extraction Locations**

A key consideration for ETR systems is the location where water will be extracted from the aquifer. In general terms, extraction can take place either at the leading edge of the plume or within the plume footprint.

Leading Edge. For most plume geometries, leading edge extraction offers the most cost effective method of plume containment because the system relies on the ambient flow conditions to move contamination to the capture zone. Conversely, it is the most expensive option when it is rated on the basis of cost per unit mass of contaminant removed. This is because the extracted water generally has low contaminant concentrations. Wells are positioned to capture all known contamination as the plume flows downgradient, but if the plume trajectory changes, it may bypass the wellfield or become smeared across the aquifer.

In-Plume. In contrast to leading edge extraction wells, in-plume wells aim not at containment, but by focusing on the areas of greatest contamination, they maximize short-term contaminant mass reduction. In-plume extraction wells shorten the time required for remediation by reducing the distance contaminants travel to the pumping well. The axial fence at FS-12 is based on this principle.

The use of leading edge extraction wells and in-plume extraction wells, and a combination of both will be considered for each area of contamination in the SWOU study area. Remedial action objectives and potential environmental impacts caused by water table drawdown will be the driving forces behind extraction well location decisions. The suitability of individual extraction locations (in three dimensions) will be evaluated using groundwater modeling.

### 3.2.3 Pretreatment Technologies

There are two general reasons for including a pretreatment process: (1) to reduce contaminant levels and thus reduce the contaminant loading on the primary treatment process and (2) to condition the water so that the primary treatment process is more efficient and economical. Pretreatment should only be used when the primary treatment system requires it to be able to achieve design goals or when the reduction in the life cycle costs of the primary treatment system is greater than the life cycle costs of pretreatment.

Recent experience constructing and operating ETR systems to treat contaminated groundwater at MMR has demonstrated the importance of using a modular approach. Irregularities in the aquifer and contaminant distribution and differences in the chemical composition of water removed from the aquifer under low-flow sampling techniques and high-flow extraction techniques may result in over estimation of the need for pretreatment. Thus, unless the need for pretreatment is demonstrated prior to construction, only required process units should be built. If operational experience demonstrates the necessity or cost effectiveness of pretreatment, pretreatment process units will be added. At MMR pretreatment may be required to reduce iron and manganese loading on carbon beds.

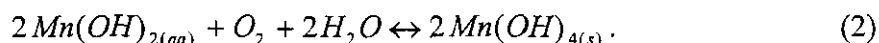
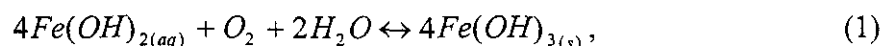
Iron and Manganese. Iron and manganese are naturally present in sediments throughout the Mashpee Pitted Plain and the Buzzards Bay Moraine (AFCEE 1998c). In locations free of groundwater contamination, these metals tend to be present in their oxidized, insoluble form. When organic contaminants are present in the aquifer, they can serve as electron donors for a variety of biologically mediated reactions. These reactions in turn consume oxygen and other electron acceptors, reduce the oxidation reduction potential (ORP) of the groundwater, and create a situation in which iron and manganese convert to their reduced, soluble form.

There is no Massachusetts primary drinking water standard for iron and manganese (DEP 1998), but they are covered under secondary MMCLs (300 µg/L for iron and 50

µg/L for manganese). When metal concentrations are below their respective MMCL, there is no legal requirement to remove the metals; nor is there any known health concern. However, there may be operational considerations that make metal removal desirable.

As long as iron and manganese remain in their dissolved state, they will not create a problem for a treatment system. But treatment systems can cause metals to become insoluble and, as solids, metal precipitates will cause fouling of well screens, pipes, instruments, filters, and tanks.

Iron and manganese solubility is primarily a function of concentration, pH and ORP. When these factors change, the metals will come out of solution according to the following solubility reactions (Driscoll 1986):



When highly contaminated (low ORP) waters are mixed with less contaminated (high ORP) waters, the increase in ORP may oxidize the dissolved metals and cause them to precipitate. This interaction may take place throughout the treatment train, but mixing in the well and the extraction pipeline make the well screen, well vault piping and instrumentation, and extraction pipeline header particularly susceptible to fouling.

Several other influences can also reduce the solubility of iron and manganese. The addition of reagents that affect pH or ORP can cause metals to come out of suspension. A change in pressure can also cause iron and manganese to precipitate. Process waters are frequently exposed to atmospheric gases—for instance, when they free-fall into an influent tank or when they pass through an air stripper. Exposing groundwater to atmospheric oxygen increases ORP; exposing groundwater to atmospheric carbon dioxide generally decreases pH (unless the groundwater is supersaturated with carbon dioxide, in which case it will raise the pH). Both of these effects influence iron and manganese solubility.

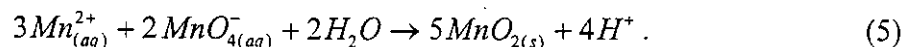
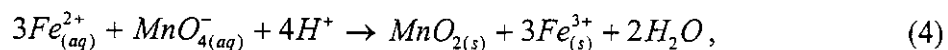
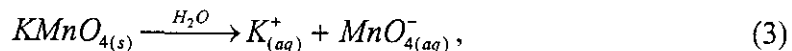
When influent iron and manganese levels are sufficiently low, such as those at the FS-28 EW-1 treatment facility, it is generally preferable from both a cost and operational standpoint to keep these metals in solution throughout the extraction, treatment and reinjection process. This determination is a key decision point in the design of each treatment train.

Remedial alternatives developed and evaluated in this FS assume that for ETR systems, influent concentrations of iron and manganese will approximate a weighted average of iron and manganese concentrations found in the volume of water to be extracted. Experience at MMR, particularly in treating the FS-12 and FS-28 plumes, suggests that this may not be the case. For instance, before system start-up, the average concentration of iron present in extraction wells at FS-12, weighted by their design flows, was 278 µg/L. Actual iron influent concentrations in extraction wells have consistently been an order of magnitude lower.

If ETR systems are included in selected alternatives, they should be constructed on a modular basis. If there is any question about the necessity of removing iron and manganese, only the primary treatment unit should be constructed initially. If operational monitoring reveals the need for a pretreatment system, it should be installed on an as-needed basis. Cost estimates in this study include funding for the pretreatment modules if current monitoring data indicate that the modules are likely to be required.

#### **3.2.3.1 Greensand Filtration**

The purpose of greensand filtration is to remove iron, manganese, and filterable solids from the treatment stream prior to primary treatment. Potassium permanganate (and possibly chlorine) must be injected upstream of the greensand filter vessels. Potassium permanganate (KMnO<sub>4</sub>) is a strong oxidant. It serves to oxidize dissolved iron and manganese (AFCEE 1997c):



Potassium permanganate has the additional benefit of acting as a biocide and helps prevent biological fouling later in the process stream. Greensand filters are generally run in down-flow mode (water enters the top of the vessel and exits from the bottom of the vessel), and periodic backwashing is necessary to remove accumulated materials.

As the influent stream enters the top of the filter, it encounters a layer of coarse anthracite typically 6-10 inches deep (Green 1997). The anthracite captures some suspended solids and any metals that have come out of suspension due to oxidation. As the run cycle progresses, a blanket of filtered material (referred to as the *schmutzdecke*) builds up on top of the anthracite and improves filter efficiency as particles are trapped within the blanket. Beneath the anthracite is a layer of manganous oxide-coated glauconite greensand approximately 18-30 inches deep. Greensand not only acts as a physical filter, it also serves as a storage bank for equivalents of oxidation introduced as potassium permanganate. Thus, short-term excesses or shortages of the reagent should not affect filter performance. The redox reactions for iron are catalyzed by the greensand, and the products are captured by the media as precipitants. Reduced manganese is captured by the ion exchange capabilities of the media (Green 1997).

Greensand filtration has been used successfully, although not without difficulties, at the FS-12 and Storm Drain-5 (SD-5) treatment plants. Filters at both sites have seen reduced flow capacity and increased backwash frequency due to the accumulation of masses of glutinous fines within the filter media. These masses may be iron bacteria biomass that has survived despite the continuous injection of potassium permanganate. However, the filters have reliably removed both iron and manganese to below the levels required for efficient carbon adsorption. Therefore, this technology will be retained for alternative development.

### 3.2.3.2 Air Stripping

Air stripping is commonly used to remove volatile components from water. For groundwater remediation, air stripping is typically conducted in a packed tower or tray tower. In both systems water enters the top of the treatment vessel and air is injected from the bottom. This countercurrent flow optimizes the driving force for mass transfer across the length of the stripper. A packed tower will typically have spray nozzles at the top to distribute the influent over a packing material consisting of variously shaped balls, rings, or saddles. The packing material can be constructed from a variety of materials and is designed to maximize the effective surface area of water passing through the tower and to maximize air turbulence. The inside wall of the tower typically has several redistributors to prevent the water from simply running down the wall (Corbitt 1990). A fan forces air countercurrent to the liquid flow, and a sump at the bottom of the tower collects the treated water. In a tray tower, water flows across the trays and air passes up through the water on the trays.

Because air strippers create a highly oxidizing environment, they are particularly susceptible to fouling. In a packed tower, fouling may fuse individual pieces of packing together and require cleaning or replacement of the packing. Trays are less susceptible to fouling and are easier to clean if fouling does occur (Mittelhauser Undated). Because of their ease of cleaning, tray towers could potentially be used for the oxidation of iron and manganese. However, even tray tower operation will be labor intensive for water with high iron levels. Below a pH of about 9, manganese precipitates very slowly, and it may be necessary to raise the pH to speed this reaction if manganese removal is desired (Peavy et al. 1985).

Henry's Law constant and solubility are often used as a measure of the potential effectiveness of air stripping on a particular contaminant (Chidgopkar 1996, Lamarre and Shearouse 1996). Generally, organic compounds with Henry's Law constants greater than 0.01 atmosphere-m<sup>3</sup>/mol (556 atm) are considered amenable to air stripping (DOE 1998). For a given Henry's Law constant, the lower the compound's solubility, the easier it is to air strip. Table 3-1 lists Henry's Law constants and

solubilities for CCl<sub>4</sub> and EDB (Montgomery and Welkom 1989). A review of this table suggests that air stripping is an appropriate technology for removal of CCl<sub>4</sub>, except in cases in which they are combined with less volatile compounds, such as EDB.

**Table 3-1**  
**Physical Properties of Organic Contaminants of Potential Concern**

<b>Contaminant</b>	<b>Solubility (mg/L at 20°C)</b>	<b>Henry's Law constant (atm-m<sup>3</sup>/mol)</b>
carbon tetrachloride (CCl <sub>4</sub> )	800	0.024 at 20°C
1,2-dibromoethane (EDB)	4321	0.000706 at 25°C

atm-m<sup>3</sup>/mol = atmosphere x cubic meter per mol

When successful, air stripping transfers contaminants from the aqueous to the vapor phase. Subsequent vapor phase activated carbon filtration may be required to capture the vapors from the air stripper. Vapor phase carbon has a greater capacity for holding contaminants than liquid phase activated carbon.

Removal efficiencies of 99 percent are possible for stripping towers that have 4.6 to 6 meters (15 to 20 feet) of packing and are treating highly volatile compounds, such as CCl<sub>4</sub> (DOE 1998). Removal efficiencies will be lower during periods of lower temperatures. Due to lower effective surface areas, tray towers generally have lower efficiencies. Removal efficiency can be improved by operating strippers in series, increasing the air-to-water ratio, or by heating either the air or water.

Several factors may affect the implementability of air strippers. Neighbors may object to both the noise generated by rapidly moving large volumes of air and the vessels' height. (Low-profile tray towers are available, but are also noisy.) Freezing during winter months is also a potential problem.

Air stripping, particularly using tray towers, has the potential to be an effective method of removing metals, and is efficient for removing CCl<sub>4</sub> at high concentrations. However, it is not efficient for EDB. For metals removal, other pretreatment processes are more effective. Because of the presence of EDB in the FS-28 and

FS-29 plumes, air stripping will not be considered as a pretreatment for alternative development.

### **3.2.3.3 Sand Filters**

As a pretreatment process, sand filters could be used to remove iron and suspended solids. Filtration removes solid particles based on their size by forcing the fluid through a porous medium. The media generally consist of silica sand with a gravel under drain. Anthracite coal may be used as a top layer to capture larger particles. As the filter's run cycle progresses, a blanket of solids accumulates in the upper layers of the bed. As this blanket develops, filtration efficiency improves. However, as the blanket thickens, head loss across the filter increases, causing the need to backwash the filter. Expended backwash water is pumped to a cone bottom tank for settling.

For metals removal, this process can be optimized through the addition of an oxidant, a coagulant, and pH control, or some combination of these. An oxidant, such as potassium permanganate, would convert ferrous iron into insoluble ferric iron. Precipitated ferric iron that is suspended in solution would be removed by the filtering action of the sand. For the low-carbonate (generally 8-12 mg/L as  $\text{CaCO}_3$ ) groundwater present in the SWOU area, iron reaches its minimum solubility at a pH of approximately 8 (Pankow 1991). Commonly used coagulants include alum, ferric chloride ( $\text{FeCl}_3$ ), organic polymers and synthetic polyelectrolytes (FRTR 1997). Coagulants generally use electrostatic attraction to allow small suspended particles to agglomerate. A mixing tank and flocculation tank would be required prior to sand filtration.

Although sand filters could be used for pretreatment, they have the same disadvantages as greensand filters and with fewer benefits. Fines resistant to backwashing would have the same tendency to agglomerate within sand filters as they do in greensand filters. Silica sand lacks greensand's ability to act as an ion exchange media and to store equivalents of oxidation. For these reasons, sand filtration processes will not be considered in developing remedial alternatives.



### **3.2.3.4 Settlers and Clarifiers**

Settlers and clarifiers remove suspended particles from water by gravitational settling. As in sand filtration, the addition of an oxidant, a base, or a coagulant or a combination of these followed by mixing and flocculation could be used to improve settler efficiency. Materials to be removed include both suspended solids present in the plant influent and dissolved solids that have precipitated during previous treatment. Ferric hydroxide ( $\text{Fe}(\text{OH})_3$ ) and manganese oxide ( $\text{MnO}_2$ ) formed due to the addition of potassium permanganate or other oxidizers fall into the second category.

For the low sediment loads present in groundwater, two settling phenomena are of importance: discrete settling and flocculent settling. Discrete particle settling occurs primarily with sand and grit. These particles settle as individual units with no significant interaction between particles. On the other hand, the precipitation process generates very fine particles that are held in suspension by electrostatic surface charges. Chemical coagulants are often added to overcome these repulsive forces. After coagulant addition and rapid mixing, low shear mixing in a flocculator promotes contact and particle agglomeration. Flocculation increases particle mass which in turn decreases particle settling time.

Settling generally occurs in a separate tank from flocculation. Sludge from the bottom of the tank is pumped to a sedimentation tank for thickening and disposal.

Although, like sand filtration, settling would not remove manganese from solution, it could be an effective process to remove precipitated iron and suspended solids. The process has a long history of use in water treatment and would be easily implemented to help treat MMR-related contamination. Settlers have a larger space requirement than other pretreatment options. However, unlike greensand and sand filters, settlers are open vessels. Operational difficulties can be easily assessed and corrected. Settlers have capital costs that are similar to other pretreatment options, and they have somewhat lower operating costs. Settlers will be considered in developing remedial alternatives.

### 3.2.3.5 Ozone Injection

Ozone is highly reactive and a powerful oxidizing agent. When the three-atom form of oxygen encounters another compound, one atom will tend to break away, attach itself to the compound and oxidize it. The remainder of the ozone molecule returns to molecular oxygen. Because of its tendency to break down quickly, ozone cannot be stored or transported and must be generated on site. Ozone is produced with corona discharge technology which ionizes pure oxygen or clean, dry air in a high energy electric arc (Peavy et al. 1985):



Because ozone has low solubility in water, it must be mixed thoroughly to ensure adequate contact with the contaminant.

Negative aspects of ozone injection into influent water include high energy costs and the tendency to oxidize soluble iron and manganese. In contrast, several properties may make it beneficial as a pretreatment process. Ozone acts as a biocide. It kills bacteria cells by lysing, rupturing cell membranes and dispensing cell cytoplasm into the water. This helps to prevent the formation of colonies of iron bacteria in subsequent treatment processes, and in contrast to chlorine injection, no potentially harmful products are usually produced. Ozone also acts as a flocculent, aiding in the coagulation, filtration and settling of solids (EDC Undated). Combined with its ability to oxidize metals, this effect tends to cause filterable solids to accumulate on top of subsequent adsorption beds where they can be easily removed through backwashing.

Ozone pretreatment is most beneficial when used to treat high influent contaminant concentrations. As discussed in Section 1.1, contamination within the SWOU study area is generally at low levels. Assuming that the maximum contaminant detections (Tables 1-2 and 1-3) approach the maximum levels present in the aquifer, any

treatment system installed will see even lower levels of contamination because of dilution by radial flow into the extraction wells and because of dilution by water extracted from less contaminated wells. The cleanup itself will result in lower influent concentrations over time. Because of the probability of low influent concentrations, ozone injection will not be considered during the development of remedial alternatives.

### **3.2.4 Primary Treatment Technologies**

The goal of primary treatment is to remove or destroy the contaminants of concern. The ensuing discussion covers the following types of systems: air stripping, activated carbon, synthetic carbon, ultraviolet oxidation, and mobile carbon.

#### **3.2.4.1 Air Stripping**

Air stripping could be used as a primary treatment, as it is effective in removing volatile organics. As the primary treatment, treatment efficiency would be limited by the least volatile contaminant of concern found at each location. Because of the presence of EDB in both the FS-28 and FS-29 plumes, air stripping will not be considered when developing remedial alternatives.

#### **3.2.4.2 Liquid Phase-Activated Carbon Adsorption Systems**

Activated carbon adsorption, an ETR treatment option, removes organic materials from water by adsorption, the attraction and accumulation of one substance on the surface of another. Activated carbon is manufactured from carbonaceous material such as coal or wood. The material is initially pyrolyzed, burned in a limited oxygen environment, and then oxidized at higher temperatures to create a very porous structure (Peavy et al. 1985). This second step, referred to as activation, produces a network of submicroscopic pores in which adsorption takes place. A single pound of activated carbon may contain an effective total surface area of over 100 acres, allowing it to trap large quantities of organic liquids and vapors under ideal conditions (Calgon 1993).

As water passes through porous granules of carbon, contaminant molecules are attracted to the surface of the pores and held there by weak chemical, physical or electrostatic forces, or a combination of these forces. Chemical bonding, when it occurs, is relatively irreversible. The attractive physical forces, known collectively as London Dispersion Forces (a type of Van der Waals force), are the same forces responsible for surface tension and condensation of vapors into liquids (Calgon 1993). Electrostatic attraction increases as the ion charge increases (note the +2 charge on ferrous iron and manganese oxide) and as the hydrated ionic radius decreases. When held by either physical or electrostatic attraction, the adsorbate is not fixed to a specific site and the adsorption is reversible (Gossett 1996). When an adsorber system runs beyond breakthrough, more weakly adsorbed components can be desorbed into the effluent. Resulting concentrations may exceed influent concentrations (Calgon 1993). To ensure that no contamination is present in the effluent, it is advisable to maintain reserve adsorption capacity.

Activated carbon adsorption systems at sites under the jurisdiction of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) are generally operated in series so that all water flows through a pair of vessels, a lead adsorber and a polishing adsorber (Figure 3-4). Initially, the contaminants are adsorbed onto carbon in the upper portion of the lead bed. As this top layer of carbon becomes saturated, adsorption takes place lower in the bed. Eventually all the carbon in the lead adsorber becomes saturated and the contaminant concentration in the effluent of the adsorber increases until it approaches or equals the influent concentration (breakthrough). Alternately, breakthrough may be defined as the effluent concentration from the lead adsorber equal to or greater than some discharge standard. Operational samples are generally taken between the pair of carbon vessels. Once breakthrough has occurred in the first vessel, the carbon in that vessel must be replaced and the flow redirected so that the polishing adsorber becomes the lead adsorber and the former lead adsorber (with fresh carbon) becomes the polishing adsorber. This method of operation ensures that the polishing adsorber always contains a reserve of adsorption capacity.

Spent carbon is routinely returned to the manufacturer for regeneration. The process of regeneration results in the destruction of organic contaminants by exposing the spent carbon to a high temperature oxygen-deficient environment.

The organic carbon partition coefficient is commonly used as an indicator of a chemical's affinity for adsorption onto activated carbon. The organic carbon partition coefficient is defined as the ratio of the concentration of organic chemical adsorbed onto organic matter to the equilibrium concentration of the same chemical in the aqueous phase. The organic contaminants of concern in the FS-28 and FS-29 plumes are amenable to carbon adsorption (Table 3-2) (Montgomery and Welkom 1989).

**Table 3-2**  
**Organic Carbon Partition Coefficient**

<b>Contaminant</b>	<b>Organic Carbon Partition Coefficient Log K<sub>oc</sub> [cm<sup>3</sup>/gm]</b>
carbon tetrachloride (CCl <sub>4</sub> )	2.35
1,2 dibromoethane (EDB)	1.64

cm<sup>3</sup>/gm = cubic centimeter per gram

Granular-activated carbon is moderately expensive. Its capacity for holding contamination is a function of contaminant concentration, the presence of other molecules of similar size, the consistency of the influent stream over time, and the adsorbability of the contaminant. Economical use of carbon on highly contaminated waste streams and waste streams with high total suspended solids (greater than 5 to 10 mg/L) or metals (greater than approximately 1 mg/L filterable metal) requires pretreatment (Personal communication between J. Rapurto of Calgon Carbon Corporation and S. Witzmann of Jacobs Engineering, 1998). For dilute waste streams with low total suspended solids and filterable metals, where pretreatment is not required, activated carbon treatment is cost competitive when compared to other technologies.

Carbon treatment units have been used to effectively treat contaminated groundwater from MMR. They are currently being used in the systems installed to treat the FS-12, SD-5, CS-4, CS-10, and FS-28 groundwater plumes. The wellhead treatment system

installed at the CWSW also relies on liquid-phase carbon adsorption. Carbon treatment systems are particularly well suited for conditions in which concentrations in the influent are relatively low so that carbon requirements are low.

Carbon systems are readily available and could be implemented for any of the groundwater contamination plumes in the SWOU study area. When contact time is sufficient, carbon adsorption is capable of removing organic contaminants to non-detectable levels. Carbon adsorption is a feasible treatment process for CCl<sub>4</sub> and EDB contamination and will be considered for alternative development.

A wide variety of activated carbon adsorption vessels is commercially available. However, a modular system incorporating this technology has been designed specifically for use on groundwater contamination from MMR. The carbon adsorption module is capable of treating 600 gallons per minute (gpm). Section 3.2.4.5 describes a mobile carbon adsorption system capable of treating 100 gpm. During development of alternatives, the simplifying assumption has been made that if carbon adsorption is used, it will be implemented using one or both of these systems, or multiples thereof. Thus, for capital costs, treating 900 gpm will be considerably more expensive than treating 600 gpm. Both systems would require two modules of carbon adsorption, each treating 600 gpm. On the other hand, capital costs for treating 1200 gpm will not be substantially more expensive than the cost of treating 900 gpm.

Lead. EDB and elevated lead levels have been noted in several wells at the distal end of the FS-28 plume. While both EDB and tetraethyl lead were common fuel additives during the period when FS-28 plume contaminants are believed to have been released, the distribution of lead in FS-28 groundwater could also be an environmental anomaly, resulting from conditions of which we are unaware. It is beyond the scope of this study to either prove or disprove that lead at the distal end of the FS-28 plume originated on MMR.

However, because of the co-location of the two contaminants, efforts taken to capture EDB contaminated groundwater may also capture lead. Treatment system effluent must comply with regulatory standards for lead discharge.

During development of the EW-1 extraction well for the FS-28 treatment system, system influent was analyzed for total lead. The result (76.9 µg/L on October 3, 1997) was well above regulatory standards. Both the Commonwealth of Massachusetts and the federal government have established action levels of 15 µg/L for lead in tap water. The system started on October 14, and on October 28 influent was again analyzed for total lead. At that time the result (6.2 µg/L) was below regulatory standards. A third sample collected on April 15, 1998 did not have detectable levels of total lead. These results could be a function of the differences between samples collected under low flow conditions and samples collected from a high-flow extraction pump. However, in this case, three data points are an insufficient basis for far reaching conclusions.

In addition to organic contaminants of concern, the possibility exists that a treatment system designed to treat the FS-28 plume could extract water containing elevated levels of lead. Numerous studies have been conducted on the ability of granular-activated carbon to remove lead (Kuennen et al. 1992). Four mechanisms have been cited as contributing to the removal of lead from water with activated carbon: (1) adsorption of  $Pb^{+2}$  and its hydroxometallic complexes ( $Pb(OH)_x^{2-x}$ ); (2) hydrogen bonding of these hydroxometallic complexes with the carbon; (3) chemical precipitation within the porous carbon structure; (4) and physical removal (straining) of insoluble lead compounds and complexes. Removal efficiency appears to be strongly dependent on pH. Corapcioglu and Huang (1987) demonstrated that the amount of lead adsorbed increases from a low value to nearly 100 percent over a narrow range of increasing pH. This range was referred to as the pH adsorption edge and is specific to the type of carbon employed. The adsorption edge for lead was found to be from pH 3 to 6 for the majority of carbons tested. If lead is present in system influent, it is expected to be easily removed with granular-activated carbon. If the activated carbon fails to reduce effluent lead concentrations to acceptable levels, a

small increase in pH should increase system capture efficiency to acceptable levels. A different type of carbon may also be able to more effectively remove lead at the influent pH.

Since lead is present within the leading edge of the FS-28 plume, treatment system designs for this plume must account for its presence. Captured lead (in excess of regulatory standards) must be removed during treatment.

#### **3.2.4.3 Synthetic Carbon Adsorption Systems**

Several vendors manufacture substances intended to have adsorption capabilities that are superior to activated carbon. These substances are collectively referred to as synthetic carbon. Two of these are Ambersorb and Nochar.

Ambersorb. Manufactured by Rohm & Haas Company, Ambersorb Type 563 is composed of hard, black, spherical beads. These beads have a fine particle size on the order of U.S. Sieve Size 20 to 50. Ambersorb has a higher removal capacity than activated carbon, and also displays faster adsorption kinetics (Rohm & Haas 1992). The manufacturer claims that Ambersorb has five to 10 times the adsorption capacity of activated carbon when used to capture TCE and PCE at concentrations of less than 10 mg/L. Faster kinetics mean that smaller tanks are possible. The manufacturer also claims that Ambersorb is resistant to biological fouling. However, Ambersorb is much more expensive than an ETR system with carbon adsorption. When purchased in bulk, Ambersorb is 40 to 50 times more expensive, per pound, than activated carbon (according to a July 21, 1998 phone quotation from Fahrenthold & Associates, Inc., an Ambersorb distributor).

Ambersorb is a developing technology and has never been installed in a full sized plant. The largest application to date has a total flow of only 40 gpm. Several potential problems exist with using Ambersorb in a full size adsorber. The manufacturer recommends prefiltration to avoid fouling problems. Backwashing is not recommended during the service cycle because the manufacturer is not confident



that the bed will properly reclassify at the end of the backwash cycle. Finally, although Ambersorb can be regenerated on-site, the process is not simple.

For other applications (the FS-12 and SD-5 plumes), the distributor Fahrenthold & Associates, Inc. has recommended that Ambersorb be regenerated with industrial grade methanol or acetone (letter dated August 13, 1996 from Michael Fahrenthold of Fahrenthold & Associates, Inc. to Stephen Frost of Jacobs Engineering). This process would necessitate hazardous materials storage for both process and waste chemicals. Thus the storage tanks would need to be located in an isolated section of the treatment plant. Condensed contaminants could be recovered through phase separation (Roy F. Weston, Inc. Undated). Finally, the waste chemicals would need to be shipped offsite for recycling or disposal. Because of the complexity of the treatment train, and because Ambersorb has not been proven in a full scale plant and cannot be backwashed, further consideration of this product is not warranted at this time.

Nochar. Manufactured by Nochar, Inc., Nochar A620 is another form of synthetic carbon. Nochar is a mixture of polymer and activated carbon. Contaminants absorb to the Nochar, polymer in contrast to the reversible adsorption that takes place in the carbon pores. Like Ambersorb, it has better capture capacity and kinetics than activated carbon. It is also approximately 20 times more expensive than activated carbon.

Nochar is comprised of approximately 58 percent polymer particles and 42 percent virgin activated carbon. When the product is initially shipped, the two types of particles are bonded together with a neutral, water soluble adhesive to ensure uniform mixing. (The adhesive is a combination of water and Elmer's Glue.) As the polymer particles absorb contaminants, they expand. The primary purpose of the activated carbon is to maintain hydraulic pathways through the media. High differential pressures indicate that the media is nearing its contaminant saturation point and must be replaced.

Treatment takes place in a pressure vessel. In previous applications the filter bed consisted of (from bottom to top) of a layer of gravel, commercially available filter material (commonly referred to as hog's hair), Nochar, a second layer of filter material, and gravel. Nochar is highly hydrophobic and, if allowed, a portion of the bed will float in water. Thus the second layer of filter material and gravel (10 pounds per cubic foot of Nochar) is required to ballast the Nochar. Because the ballast will sink and the polymer and activated carbon will separate, it is not possible to backwash this media. Activated carbon treatment systems installed at the FS-12 and SD-5 treatment plants and located downstream from greensand filters currently require backwashing approximately every six weeks. The application of similar pretreatment systems for other plumes would not allow the use of Nochar.

Nochar has never been installed in a full sized plant. The largest application to date is 150 gpm. In addition to difficulty in backwashing, there are a number of potential difficulties to operating larger scale Nochar filters. Despite the presence of activated carbon, there is no guarantee that the expansion of the polymer particles will not prematurely cause differential pressure buildup and reduced flows. Additionally, Nochar cannot be regenerated. The spent media must either be incinerated or, if it fails to meet Toxicity Characteristic Leaching Procedure (TCLP) standards, landfilled. Afterwards, the entire bed must be manually reloaded.

If the manufacturer's claims of absorption capacity are correct, the use of Nochar could result in a significant savings in comparison to activated carbon. Activated carbon vessels in treatment systems recently constructed at MMR contain an air scour header that holds the potential to allow the development of a hybrid Nochar – activated carbon filter bed that could avoid the need to backwash the Nochar material. AFCEE is currently considering a pilot test for Nochar. However, due to a lack of experience in a full sized facility, Nochar does not warrant further consideration during the development of alternatives at this time.

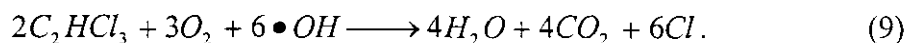
### 3.2.4.4 Ultraviolet/Oxidation Treatment Systems

Ultraviolet/oxidation (UV/OX) systems destroy VOCs in groundwater through chemical oxidation enhanced by exposure to ultraviolet light. This process has several advantages over competing technologies. In addition to on-site contaminant destruction, UV/OX systems have no vapor emissions, so no air permit is required. The equipment is also quiet and compact.

Reagents used with UV/OX typically include hydrogen peroxide and ozone. When the oxidants are exposed to intense ultraviolet light, photolysis occurs and hydroxyl radicals are produced (CCOT 1997). For instance:



The presence of hydroxyl radicals initiates a cascade of oxidation reactions. If taken to completion, contaminants such as PCE and EDB are transformed into end products consisting mainly of carbon dioxide and water, with small amounts of chloride and bromide. For example, TCE is degraded according to a series of reactions that may be generalized as:



Under some conditions, pretreatment may be required upstream of the UV/OX reactor (CCOT 1997). Suspended solids reflect and absorb ultraviolet light, reducing treatment efficiency. If suspended solids are greater than 50 mg/L, pretreatment, such as filtering or clarification, is generally recommended. High iron levels (more than 50 mg/L) compete with target contaminants and hydrogen peroxide for ultraviolet energy, decreasing treatment efficiency. However, UV/OX can benefit from dissolved iron due to the Fenton reaction (UND 1996). Therefore, if iron is present in the water at greater than 5 mg/L, it may be beneficial to maintain iron in solution by reducing pH (Calgon 1996).

Completion of the oxidation process to mineralization results in on-site destruction of the organic contamination. This offers an advantage over competing technologies such as activated carbon, in which the media must be disposed of offsite or regenerated. For chlorinated alkenes such as PCE and TCE, mineralization rates of 98 percent and 70 percent, respectively, have been reported (EPA 1992). The process is not as effective for EDB. Tests conducted on water from the FS-12 plume indicate that EDB destruction rates of greater than 50 percent can only be obtained through extremely high energy expenditures (AFCEE 1996). These destruction rates mean that a polishing step, such as activated carbon, will be required following UV/OX to reduce contamination concentrations to non-detect.

Experience at the FS-12 treatment plant reveals two problems with this set-up. First, because of very high energy costs associated with the high intensity UV/OX lamps, the savings in reduced carbon requirements is only sufficient to justify using UV/OX technology when influent concentrations remain consistently above approximately 1,000 µg/L. For the FS-28 and FS-29 plumes, it is not anticipated that plant influent would contain contaminant levels high enough to justify the costs of a UV/OX system. Second, the reactions initiated by the photolysis continue after water leaves the UV/OX reaction vessel. This means that oxygen and carbon dioxide concentrations in the UV/OX effluent may be high enough to cause effervescence. When this occurs in a bed of activated carbon, gas bubbles form both above and within the bed. The bubbles above the bed may be alleviated with a gas relief valve, but those within the bed can cause channeling and early breakthrough of the carbon. Although it may be possible to alleviate this problem with an additional atmospheric pressure tank located between the UV/OX system and the activated carbon vessels, further consideration of this technology is not justified in light of the associated costs and operational difficulties.

#### **3.2.4.5 Mobile Carbon Adsorption Systems**

The design of a remedial groundwater extraction and treatment system is, by its very nature, a risk management effort. Even the most thorough investigative efforts cannot answer all questions concerning lithology, hydrology, and contaminant distribution.

Even a properly designed ETR system has decreasing influent contaminant levels over time because of dispersion, soil matrix sorption and desorption equilibria and kinetics, and direct cleanup effects. To minimize these difficulties, mobile carbon treatment systems could be used.

The idea behind mobile carbon adsorption systems is an extension of the idea behind modular treatment systems, and they share many of the same benefits. Both types of systems are adaptable to the surrounding terrain and can be placed close to wells, minimizing extraction pipeline lengths. They have simple controls and reduced construction requirements, that allow for compressed schedules. For the purpose of this discussion, it is assumed that each mobile treatment system would have a capacity of approximately 100 gpm, compared to the AFCEE modular system which was designed with a capacity of 600 gpm.

Mobile treatment systems can be trailer or skid mounted. If commercial electric power is unavailable, extraction pumps could be powered by a diesel electric generator. Extraction cannot take place directly from existing 2 ¼-inch monitoring wells, because they are not large enough to accommodate a submersible pump capable of handling 100 gpm. The depths involved within the SWOU are too great to make the use of suction pumps feasible. Therefore, an 8-inch well would have to be installed inside of a 12-inch gravel-packed boring. The treatment system itself could be installed in the immediate vicinity of the extraction well. Treated water would be discharged to an infiltration gallery or reinjection well designed to minimize dispersive effects of the treated water. Depending on the distances and costs involved, either a separate infiltration gallery could be used for each extraction well, or a centralized infiltration system could be constructed. Each system would need to be winterized, and if requested, vendors would need to be able to supply pretreatment units, such as greensand filters or air strippers, rapidly. Treatment would continue in each location until either the remedial objectives had been met, or until a location suitable for this type of treatment with higher levels of contamination was located. Multiple systems could be used in different locations, depending on the level of effort required to meet remedial objectives.

Mobile carbon treatment could be prioritized for in-plume mass reduction efforts. This technology is less appropriate at leading edge (containment) locations because of the longer treatment periods involved. Pumping rates would be limited by system size. The system would have high sampling costs because it is anticipated that an initial influent sample and weekly samples taken between the carbon beds would be required. Additional influent samples would be required on a monthly basis. During operations, mobile systems are also more manpower intensive than permanent facilities and require operator attention on a daily basis for such tasks as generator refueling.

There are several advantages to mobile carbon treatment systems. Contamination in the SWOU study area is highly dispersed. A mobile treatment system can focus remediation efforts on the most contaminated areas and achieve mass reduction. Mobile carbon treatment would minimize expenditures for investigations and thus maximize the proportion of funds spent on actual cleanup efforts. The systems have low capital costs and could potentially be rented from vendors and returned when no longer needed. The greatest benefit of mobile carbon treatment systems is their flexibility. Because of their ability to quickly focus on the areas of highest contamination and their flexibility in adapting to changing situations, they will be considered in developing remedial alternatives.

#### **3.2.4.6 Low Technology Open Air Treatment**

A number of low technology treatment options were considered for possible use in conjunction with extraction and reinjection. These options included sprinkler irrigation, cascades, and the use of holding ponds. A typical implementation of these processes would involve a series of cascades leading into an open air holding pond. The cascades would allow for rapid removal of a portion of the volatile contaminants. Volatilization and photodegradation would take place in the holding pond. Aerators could be used to accelerate volatilization within the holding pond.

Potential difficulties with the implementation of these process options include:

- The space requirements for a large holding pond will be difficult to satisfy. The required volume of this pond would be the product of the system flow rate and the required holding time. The required holding time would, in turn, be a function of the contaminants present, their concentration, the ambient temperature, the maximum effluent concentration, the geometry of the pond, and the prevailing wind speed. The relative low volatility of EDB would significantly increase the space required.
- Due to the cold climate, the system would have to be shut down during freezing periods. This type of pulse treatment could potentially be used to contain and treat the plume, but would require higher flow rates during periods of treatment.
- Open bodies of contaminated water provide an exposure pathway for plume contaminants.
- Most of the contamination will not be destroyed or immobilized; it will be released to the atmosphere. It is believed that the quantities and concentrations emitted would be within regulatory limits.
- These technologies may not be effective at consistently reaching non-detectable effluent concentrations. This is especially true for plumes containing EDB.

Cost considerations include the need for two sets of pumps. One set would extract groundwater, and the second set would reinject treated water. Construction of a sufficiently large holding pond would also be a major expense. Low-technology open-air treatment may have significantly lower capital, operations, and maintenance costs than other treatment options, but effectiveness and implementability issues make it an impractical method of treating SWOU groundwater contamination.

### **3.2.5 Discharge Technologies**

Discharge technologies return groundwater to the aquifer after it has been treated to remove contamination. Potentially applicable technologies include infiltration trenches, reinjection wells, and surface water discharge.

#### **3.2.5.1 Infiltration Galleries**

Infiltration galleries or trenches consist of a network of trenches located below the frost line with distribution pipes to carry water throughout a network. The system

could be constructed with backhoe excavation, a geosynthetic drainage net, and slotted pipe. Installation with a trencher and flexible pipe is another option. The primary functional difference between infiltration trenches and reinjection wells is that infiltration trenches deliver water to the vadose zone, above the water table. This arrangement buffers groundwater both from changes in the quantity and chemistry of reinjected water. Trenches percolate water at a low enough velocity that sand grains would not be rearranged. This means that trenches can function over long periods of time with little need for maintenance. Trenches may not work in areas where the water table is shallow. The CS-4 infiltration gallery has been in operation for over five years without problems. Infiltration galleries are significantly less expensive than reinjection wells. This technology will be retained for alternative development.

#### **3.2.5.2 Reinjection Wells**

Reinjection well technology consists of a series of vertical wells connected by a distribution header, capable of injecting water directly into the saturated portion of the aquifer. Control valves can be adjusted based on data feedback from flow meters to control the discharge. Controlling discharge locations and ratios provides flexibility in the hydraulic control of the plume. Reinjection wells also can be used to minimize drawdown in ecologically sensitive areas. Reinjection wells have proven to be an effective, implementable method of discharging treated water at FS-12 and SD-5. However, the pressure required to inject water into some wells has increased over time. This may be caused by high ORP reinjected water oxidizing ferrous iron present in the groundwater. Air may also be mixing with reinjected water and becoming entrapped in the soil matrix surrounding the reinjection well screen. Such entrapped air may decrease the hydraulic conductivity of the formation. Both construction and operational costs are higher than those of infiltration trenches. Because of their past record of effective operation at MMR, this technology will be considered in developing remedial alternatives. Reinjection wells will be employed if modeling suggests that infiltration galleries will cause unacceptable mounding of the groundwater table or unacceptable dispersion of contaminants.



### **3.2.5.3 Surface Water Discharge**

Potential surface water discharge locations include Osborn, Edmunds, Coonamessett, and Deep ponds. Because Osborn, Edmunds, and Deep ponds have no surface outlets, it is expected that discharge of treated water to these ponds would cause them to rise significantly before sufficient drainage to groundwater could occur. A small stream (the Coonamessett River) drains Coonamessett Pond and runs through the cranberry bogs to the south. Although other streams do exist within the SWOU study area, none are of sufficient magnitude to be able to convey a significant portion of anticipated treatment plant effluent.

On-site discharge of treated water to a surface water body from a CERCLA site would be required to meet the substantive, but not administrative, requirements of the National Pollutant Discharge Elimination System (NPDES). Off-site discharge would be required to meet both substantive and administrative requirements. Additionally, this option may not be acceptable to the public. Long pipelines would make this option moderately expensive. Surface water discharge is currently occurring at the FS-28 treatment system and additional surface water discharge (to the Coonamessett River or Coonamessett Pond) will be considered in developing remedial alternatives for the FS-28 plume. However, because of a lack of other suitable locations in reasonable proximity of anticipated extraction and treatment locations, surface water body discharge will not be considered in developing remedial alternatives for the FS-29 plume.

### **3.2.6 Discharge Locations**

Treated water is not just an effluent to be disposed of; the careful choice of a discharge location can help establish hydraulic control, minimize plume expansion, and reduce required treatment times. Discharge locations would be selected to minimize mounding and drawdown in ecologically sensitive areas, such as ponds, vernal pools, and streams. Final selection of discharge locations should be optimized using numerical models. Upgradient, cross-gradient, downgradient, and above-plume discharge options are discussed below. Locations are relative to the plume's location.

Upgradient Discharge Locations. Contaminant concentrations in the groundwater strive to establish equilibrium with concentrations adsorbed onto the sediment matrix. Upgradient discharge provides a mechanism for flushing sorbed contaminants from the aquifer and reducing overall cleanup times. However, the FS-28 and FS-29 plumes contain only minimal amounts of sorbed contaminants. Because of the proximity of other plumes in the upgradient SWOU area, upgradient discharge could influence the trajectory of other plumes. Therefore, it will not be considered in developing remedial alternatives.

Cross-Gradient Discharge. Cross-gradient discharge locations would be chosen in an area where no other plume has been identified so that another plume would not be influenced by the discharge. Cross-gradient discharge is feasible and would be cost effective, so it will be considered in developing remedial alternatives.

Downgradient Discharge. Downgradient discharge would allow for a system design that minimizes the impact on groundwater flows. The discharge location would be chosen to minimize the impact on other plumes in the area. Downgradient discharge is feasible, cost effective, and will be considered in developing remedial alternatives.

Above-Plume Discharge. Discharge directly above the plume could minimize the required lengths of pipelines. Depending on local lithology, contaminant distribution, and groundwater flow, it may be possible to discharge treated water directly above the plume without causing unacceptable dispersive effects. Above-plume discharge may be feasible and is cost effective; it will be considered in developing remedial alternatives. Discharge below the plume is not practical for SWOU plumes because of their contaminant distributions relative to bedrock.

The exact location of discharge points used during development of remedial alternatives will be determined by numeric groundwater modeling. If the selected alternative includes ETR systems, discharge locations will be reviewed and refined during the design process.

### 3.3 RECIRCULATING WELLS

Recirculating well technology is a recently developed process used primarily for the removal of VOCs in groundwater (AFCEE 1997a). Pilot tests of this technology at MMR have been run near Sandwich Road in the CS-10 plume and in the southern portion of the Ashumet Valley plume. The technology creates a zone of vertical groundwater recirculation in the vicinity of the treatment well as a result of the extraction and reinjection of groundwater at different elevations within the same well. Under some circumstances, the creation of vertical groundwater recirculation may actively flush contaminants from the soil matrix and decrease cleanup times. Contaminants may be removed more quickly by groundwater advection rather than diffusion from layers of significantly lower hydraulic conductivity. Sorbed contaminants can also be removed more quickly through vertical flow. Recirculating well technologies can provide beneficial results when used near ecologically sensitive areas, such as vernal pools and surface water bodies, since they produce no net change in groundwater levels.

In many recirculating well systems, volatile compounds are removed by in-well air stripping. In this type of recirculating well, a vertical zone of recirculation is created when contaminated groundwater is brought into the well from the aquifer with a submersible air-lift pump (Figure 3-5). Volatile contaminants are stripped in the well casing, and the contaminated air is treated above the ground surface, typically with vapor-phase activated carbon. Vapor-phase carbon generally has a much higher *contaminant adsorption capacity than liquid-phase carbon*. The clean air stream can either be released to the atmosphere or, in the case of a closed loop system, directed back into the well for the removal of additional VOCs. Some recirculating wells use a submersible pump instead of an air lift pump to transport the influent to a stripping platform in the well vault. A potential variant of recirculating well technology would allow contaminated groundwater to be pumped to the treatment unit and treated using liquid-phase activated carbon. As with the air stripping technology, treated water would be reinjected at a different elevation in the same recirculating well.

Because of limitations in air stripping efficiency, recirculating well technology cannot achieve the required effluent concentrations in a single pass through the air stripper when VOC concentrations are high. Therefore, at higher groundwater VOC concentrations, recirculating well, air stripping technology relies on the continuous recirculation of treated water through the air stripper treatment process to eventually achieve the required effluent concentrations. Recirculation also requires higher system capacities because greater quantities of water are being treated.

Recirculating wells using air strippers must be able to strip the least volatile component present in groundwater. This requirement is similar to the application of air stripping as a primary treatment technology, as discussed in Section 3.2.4.1. EDB has a very limited stripping efficiency;  $\text{CCl}_4$  strips readily.

Recirculating wells designed with liquid-phase granular-activated carbon treatment will be included, as appropriate, in developing remedial alternatives for the plumes containing EDB in combination with VOCs.

The remedial project managers considered the use of recirculating wells at MMR (RPM 1998), as has the AFCEE Technology Transfer Division (AFCEE 1997b). These reports identified a number of areas in which ETR technologies and recirculating wells offer different advantages. Advantages of ETR systems generally include:

- larger capture zone per well,
- reduced monitoring requirements,
- less geological sensitivity (requires less complex hydraulic modeling),
- simpler design basis,
- greater treatment efficiency (due to less recirculation and no reliance on air stripping),
- more flexibility, and
- greater experience.

Advantages of recirculating wells generally include:

- induces vertical flow,
- allows for the discharge of treated water in the same well,
- for highly volatile contaminants, does not require aboveground treatment of groundwater, and
- minimal water level change, meaning less potential for ecological impact in surface waters.

Based on the findings of these studies and professional experience, the primary technical considerations for employing recirculating wells (as opposed to ETR systems) at MMR have been identified. The following considerations will be evaluated for any remedial alternative that includes the use of recirculating wells:

- Is a balancing of hydraulics (minimal water level change) required by the application?
- Is it necessary to remove sorbed contaminants from the aquifer?
- Is it necessary to remove high concentrations of contaminants from low conductivity zones?
- Is the uncertainty of predicting recirculation and capture zones offset by the benefits of using the approach?
- Can treatment goals for all contaminants be met for the particular application using air stripping?
- Does the system provide design flexibility to match characteristics uniquely important to the site application (e.g., aesthetics or belowground construction)?
- Is the approach likely to be cost effective in comparison to an ETR system?
- Can treated water be discharged above the plume without causing unacceptable levels of contaminant dispersion?
- Will the use of recirculating wells result in shorter cleanup times than an ETR system?

### **3.4 RESULTS OF TECHNOLOGY SCREENING**

The contamination of the FS-28 and FS-29 plumes can be characterized as follows:

- generally low contaminant levels (Tables 1-2 and 1-3) when considering demands to be placed on treatment process units.

- amenable to carbon adsorption (Table 3-2),
- containing components that are not efficiently removed by air stripping (Table 3-1), and
- except for the distal end of the FS-28 plume, the contamination is deep (Table 1-4).

Given these characteristics and the current state of technology, only ETR technologies and recirculating wells with liquid-phase granular-activated carbon adsorption are appropriate for remediation efforts in these areas (Figure 3-6). For an ETR system, the generalized treatment train recommended would consist of the following:

- vertical extraction wells,
- greensand filters, settlers, clarifiers, or no pretreatment,
- carbon adsorbers, and
- infiltration galleries.

Reinjection wells would be used in place of infiltration trenches if groundwater mounding is expected to have unacceptable environmental impacts. The high spatial variability of the plumes indicates that the use of mobile carbon treatment units should also be considered.

In Sections 5.0 and 6.0, technologies that remain after screening are employed as the building blocks for remedial alternatives. Alternatives, including no remediation and minimal action, are also considered. For each plume a broad range of remedial alternatives has been developed. The alternatives are then screened based on effectiveness, implementability, and cost. Alternatives that pass this screening phase are then developed and evaluated more fully. To achieve remedial objectives, an alternative will be selected for each plume based on: (1) overall protection of human health and the environment, (2) compliance with applicable or relevant and appropriate requirements, (3) long-term effectiveness and permanence, (4) reduction of toxicity, mobility and volume, (5) short-term effectiveness, (6) implementability, and (7) cost (EPA 1988).

## 4.0 DEVELOPMENT AND EVALUATION OF ALTERNATIVES

### 4.1 CRITERIA FOR DEVELOPING ALTERNATIVES

In accordance with the *Final Southwest Operable Unit (SWOU) RI/FS Work Plan* (AFCEE 1998d), remedial alternatives considered are limited to groundwater and surface water (FS-28 only) response actions, as opposed to source control actions. Criteria for developing alternatives are established by EPA (EPA 1988), and specify that the following types of alternatives be developed for each plume to the extent practicable:

- A number of treatment alternatives that reduce the toxicity, mobility, or volume of contaminants at each site. As appropriate, this range of treatment alternatives would include an alternative that removes or destroys contaminants to the maximum extent feasible, eliminating or minimizing, to the degree possible, the need for long-term management. AFCEE, with the assistance of the regulatory agencies, is working with the town of Falmouth to explore a range of possible institutional controls such as bylaw changes, moratoria on future well drilling, notice procedures, and other mechanisms. AFCEE will continue to provide the town of Falmouth and the public with up-to-date information on plume boundaries, depths, and contaminant concentrations, regardless of which remedial alternatives are selected. Institutional controls should remain in place until contaminant of concern concentrations are below cleanup standards. Cleanup standards are defined as the most stringent of MCLs, MMCLs, or risk-based standards (if no MCLs or MMCLs are available).<sup>4</sup>
- A number of alternatives that would involve little or no treatment, but provide protection to human health and the environment by preventing or controlling exposure to contaminants through engineering controls or institutional controls.
- A “no remedial action” alternative for each plume is also included. “Although a no action alternative may include some type of environmental monitoring,” according to EPA, “actions taken to reduce the potential for exposure (e.g., site fencing, deed restrictions) should not be included as a component of the no-action alternatives. Such minimal actions should constitute a separate ‘limited’ action alternative” (EPA 1988). Long-term monitoring is included in each no-remedial

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<sup>4</sup> AFCEE’s current policy allows for connection to public water supplies, delivery of bottled water, testing of private wells, or a combination of these actions only for existing wells (i.e., replacement actions). These wells must lie within 500 feet cross-gradient or 1500 feet downgradient of a groundwater plume. Under existing policy, AFCEE will not supply a connection to a water main in order to replace a potentially-threatened well if water mains were on the street when the well was installed. However, if the Board of Health allowed installation of a well over a plume, AFCEE would sample this well regularly.

action alternative. The no-remedial action alternative serves as a baseline for the comparison of other alternatives.

For each plume, a range of alternatives has been developed that is broad enough to provide a spectrum of remedial actions ranging from no remedial action with long-term monitoring to complete capture of plume contaminants. If active remedial alternatives are chosen, the following steps will be taken:

- Remediate the aquifer to federal and state drinking water standards or other risk-based cleanup levels.
- When MCLs, MMCLs or other risk-based cleanup levels are achieved and before the system is shut off, perform a risk assessment to determine if unacceptable ecological and/or human health risks are present; continue system operation and/or pursue additional measures as required to achieve acceptable risks.
- Once acceptable risks have been achieved, evaluate the technical and economic feasibility of additional remediation to approach or achieve background concentrations.

This three-step process represents requirements above normal site remediation because of the unique nature of the sole source aquifer on Upper Cape Cod.

In accordance with EPA guidance (EPA 1988), alternatives have been limited to only those that “carry some significant potential for being implemented at the site.” Initially all alternatives are screened to determine their ability to achieve remedial action objectives, based on effectiveness, ease of implementability, and cost. Alternatives that successfully pass the screening stage are developed more fully and evaluated against threshold and primary balancing criteria.

## **4.2 CRITERIA FOR SCREENING ALTERNATIVES**

At the screening stage, alternatives are evaluated against the short- and long-term aspects of three broad criteria: effectiveness, ease of implementability, and cost. The purpose of this evaluation is to reduce the number of alternatives that will undergo a more thorough and extensive analysis. Alternatives will be analyzed more generally at this phase than during the detailed analysis. During screening, comparisons are generally made between similar alternatives, the most promising of which is brought



forward for detailed analysis. For the sake of readability, the discussion of screening for alternatives that will later undergo detailed analysis has been minimized. Alternatives to be eliminated from further consideration at the screening stage receive more emphasis at this stage to explain why they do not warrant detailed analysis. As far as is practical, an effort has been made to carry a broad range of alternatives through to the detailed analysis stage.

#### **4.3 CRITERIA FOR DETAILED ANALYSIS OF ALTERNATIVES**

The National Oil and Hazardous Substances Pollution Contingency Plan (NCP) (40 CFR Part 300) presents nine criteria for analyzing the acceptability of a given alternative. These nine criteria are categorized as threshold criteria, primary balancing criteria, and modifying criteria. A rating system has been developed by AFCEE for this FS to evaluate the ability of the alternatives to meet the criteria (Table 4-1). A yes or no determination is used for each threshold criteria. Except for cost, a number between 0 and 5 is assigned to each of the primary balancing criteria, as follows:

- Criterion is fully met (5).
- Criterion is partially met (1-4, depending on the degree to which the criterion is satisfied).
- Criterion is not met (0).

Numerical values are assigned subjectively according to professional judgement and used only as a means of weighing trade-offs in balancing criteria. The highest numerical score does not necessarily indicate that an alternative is preferred. As discussed in Section 4.3.3, consideration of modifying criteria is not within the scope of this document.

**Table 4-1  
Remedial Alternative Evaluation System**

Evaluation Criteria	Standard	Value
Overall Protection of Human Health and the Environment	Protective; provides adequate risk reduction.	Yes/No
Compliance with ARARs	Complies with ARARs.	Yes/No
Long-term Effectiveness and Permanence	Contaminants are destroyed or removed; no recurrence is possible.	5
	Some contaminants destroyed, removed, or contained.	1-4
	Contaminants not removed or contained.	0
Reduction of Toxicity, Mobility or Volume through Treatment	Significantly reduces toxicity, mobility, or volume through treatment; no residuals remaining after treatment.	5
	Somewhat reduces toxicity, mobility or volume through treatment; some residuals remaining after treatment.	1-4
	Does not reduce toxicity, mobility, or volume through treatment; significant residuals remaining after treatment.	0
Short-term Effectiveness	Protective of community and workers during remediation; no environmental impacts; meets remedial clean-up objectives in less than 30 years.	5
	Somewhat protective of community and workers during remediation; limited environmental impacts; meets remedial clean-up objectives in 30 to 60 years.	1-4
	Not protective of community and workers during remediation; numerous environmental impacts; meets remedial clean-up objectives in more than 60 years or does not achieve cleanup goals at all.	0
Implementability	Proven, reliable technologies; little or no difficulty in obtaining needed approval, equipment, personnel, and materials.	5
	Somewhat unproven technologies; potentially more difficulty in obtaining needed approval, equipment, personnel, and materials.	1-4
	Unproven technologies; obtaining needed approval, equipment, personnel, and materials could be very difficult.	0
Cost	Present worth cost is listed for each alternative.	\$
State Acceptance <sup>1</sup>	To be determined.	N/A
Community Acceptance <sup>1</sup>	To be determined.	N/A

<sup>1</sup> State and community acceptance will be evaluated following comment on the proposed plan and addressed when the record of decision is prepared.

N/A = not applicable.

#### 4.3.1 Threshold Criteria

There are two threshold criteria, overall protection of human health and the environment, and compliance with applicable or relevant and appropriate requirements (ARARs). Threshold criteria represent the minimum requirements that each alternative must meet to be eligible for selection.

Overall Protection of Human Health and the Environment: This criterion assesses the overall effectiveness of an alternative and focuses on whether that alternative achieves adequate protection and risk reduction, elimination, or control. The assessment of overall protection draws on assessments conducted under other evaluation criteria, especially long-term effectiveness and permanence, short-term effectiveness, and compliance with ARARs.

Compliance with ARARs: Each alternative is assessed to determine whether it complies with applicable or relevant and appropriate requirements under federal and state laws. Appendix A presents the ARARs for the FS-28 and FS-29 remedial alternatives. Chemical-specific standards and guidance values in accordance with the ARARs are presented in Table 4-2.

Table 4-2  
Chemical Specific Standards and Guidance Values

Contaminant	Federal SDWA MCL <sup>1</sup>	Mass. Drinking Water MMCL <sup>2</sup>	Contaminant of Concern for Plumes
1,2 dibromoethane (EDB)	0.05	0.02	FS-28, FS-29
carbon tetrachloride (CCL <sub>4</sub> )	5	5	FS-29

MCL = maximum contaminant level

MMCL = Massachusetts maximum contaminant level

All values in micrograms per liter

**Notes:**

1. Environmental Protection Agency Safe Drinking Water Act (SDWA) National Primary Drinking Water Regulations per 40 CFR 141 (available on line at <http://www.epa.gov/OGWDW/wot/appa.html>).
2. Massachusetts Drinking Water Standards, Spring 1998, published by the Massachusetts Department of Environmental Protection, Office of Research and Standards, May 1998.

The National Contingency Plan outlines a number of potential grounds for waiving ARARs [40 CFR § 300.430(f)(1)(ii)(C)]. Grounds for a waiver include technical

impracticality from an engineering perspective, or that an alternative will attain a standard of performance equivalent to that required under the otherwise applicable requirement.

Of particular concern in evaluating remedial alternatives are cleanup standards. As discussed in the RI (AFCEE 1999c), the plumes have been defined according to concentrations above the MCL or MMCL. Once captured, at a minimum, groundwater will be treated to comply with the most stringent of the following standards: MCL, MMCL, or the Massachusetts Groundwater Quality Standard (314 CMR 6.00). This aquifer discharge standard is similar to that agreed to in the *Final Record of Decision of Interim Action: Containment of Seven Ground Water Plumes* (ANG 1995). Cleanup and aquifer discharge standards are presented in Table 4-3. AFCEE remains committed to the goal of only discharging treated water that contains non-detectable levels of contaminants of concern when the treatment technologies employed are capable of meeting this goal.

**Table 4-3**  
**Capture and Aquifer Discharge Standards**

<b>Contaminant</b>	<b>Maximum Detected Concentration <sup>1</sup></b>	<b>ARAR Cleanup Level <sup>2</sup></b>	<b>10<sup>-6</sup> Risk-based Aquifer Discharge Standard <sup>3</sup></b>	<b>Regulatory Aquifer Discharge Standard <sup>4</sup></b>	<b>Combined Aquifer Discharge Standard <sup>5</sup></b>
1,2 dibromoethane (EDB)	18	0.02	0.00096	0.02	0.00096
carbon tetrachloride (CCl <sub>4</sub> )	9.5	5	0.24	5	0.24

All values in micrograms per liter

Notes:

1. Maximum detected in the FS-28 or FS-29 plumes.
2. The applicable or relevant and appropriate requirement (ARAR) cleanup level is the MCL, MMCL, or Massachusetts Groundwater Quality Standard, whichever is more stringent.
3. 10<sup>-6</sup> Risk-based aquifer discharge standards are based on dermal, ingestion and inhalation cancer risk, using the exposure factors published in the Final SWOU Remedial Investigation (AFCEE 1999c).
4. Regulatory aquifer discharge standard is the most stringent of the MCL, MMCL, or the Massachusetts Groundwater Quality Standard (314 CMR 6.00).
5. The combined aquifer discharge standard is the lower of the risk-based and regulatory aquifer discharge standards.

Each alternative is individually evaluated for compliance with ARARs. Separate tables presented in Appendix A illustrate how well various alternatives comply with the ARARs.

### 4.3.2 Primary Balancing Criteria

The five primary balancing criteria are (1) long-term effectiveness and permanence, (2) reduction of toxicity, mobility or volume through treatment, (3) short-term effectiveness, (4) implementability, and (5) cost. Primary balancing criteria form the basis for comparing alternatives in light of site-specific conditions.

Long-Term Effectiveness and Permanence: Each alternative is assessed for its long-term effectiveness and the permanence of the solution. This criterion assesses the destruction or removal of contaminants, the magnitude of residual risks remaining at the conclusion of remedial activities, and the adequacy and reliability of controls to be used to manage residual risk. Under this criterion, the following subcriteria will be addressed for MMR:

- 100-percent capture of plume contaminants,
- treatment of contaminants and cleanup of the plume to background, if technically and economically feasible,
- human health and ecological impacts from any uncaptured portion of the plume,
- potential water supply impacts, and
- socioeconomic impacts.

The operational life of remedial alternatives for plumes of the magnitude of those found in the SWOU is generally from years to decades. Experience at MMR has clearly demonstrated that an understanding of the groundwater contamination present and subsurface conditions can change dramatically in much shorter periods of time. Thus, it is necessary to take into consideration the uncertainties involved in long-term estimates and predictions. This consideration is especially warranted in two areas: contaminant degradation half-lives and groundwater modeling.

Throughout the discussion of remedial alternatives, reference is made to the expected half-lives of individual contaminants in groundwater. These half-lives do not necessarily represent what is actually occurring in the Upper Cape aquifer; they are simply the most commonly cited half-lives in technical literature at this time. They do, however, contain a great deal of uncertainty and should be used with caution.

Modeling presented in this study relies on our current understanding of the subsurface environment. The accuracy of the modeling predictions decreases proportionally as the lengths of time involved increase. Such uncertainties emphasize the importance of flexibility in remedial alternatives. To help to address these uncertainties, all of the alternatives presented include groundwater monitoring to be conducted over the life of the remediation.

Reduction of Toxicity, Mobility, or Volume Through Treatment: Section § 121 (Cleanup Standards) of CERCLA states a preference for remedial actions that employ treatment that permanently and significantly reduces the volume, toxicity, or mobility of contaminants as the primary element of the action. This criterion addresses the capacity of the alternative to reduce the principle risks through destruction of contaminants, reduction in the total mass of contaminants, irreversible reduction in contaminant mobility, or reduction in the total volume of contaminated media.

The evaluation of both long-term effectiveness and permanence and reduction of toxicity, mobility, or volume through treatment relies heavily on groundwater modeling. Such modeling is capable of providing three-dimensional representations of how groundwater plumes are expected to change with time. Modeling can also provide estimates on how a treatment alternative will affect a plume.

Groundwater modeling used in this feasibility study is different from modeling that will be used to design treatments systems, if required, for the FS-28 and FS-29 plumes. The intent of the feasibility study modeling is to provide a general comparison of alternatives for individual plumes and, an understanding of how alternatives pursued for different plumes may interact. The FS modeling produces only rough estimates for total flow rates and numbers of wells to achieve specific alternative goals. Modeling at the design level, if required, will take place as part of the design process following additional data acquisition activities. Development of the model used for this study is presented in the Final SWOU FS (AFCEE 1999b). Appendix B discusses modeling scenarios that were used to evaluate various remedial alternatives.

Short-Term Effectiveness: This criterion addresses the effects of the alternative during construction and operational phases until remedial objectives are met. Each alternative is evaluated with respect to its (potentially negative) effects on community health, worker safety, and environmental quality during the course of remedial actions. This criterion also addresses the time required by each alternative until remedial objectives are achieved.

Implementability: The implementability criterion is used to assess the technical and administrative feasibility of implementing an alternative. Technical issues include the reliability of the technology under consideration, potential construction difficulties, and the availability of required services, materials, and equipment (preferably from multiple sources). Administrative issues include permitting and access for construction and monitoring.

Several administrative issues potentially affect any alternative involving construction within the FS-28 and FS-29 plumes. These issues include flooding, areas of environmental concern, and historical places. All areas under consideration for construction within Falmouth, with the exception of the FS-28 plume, have been classified as areas of minimal flooding (Zone C, FEMA 1993b). Construction north of the base boundary or within the Crane Wildlife Area falls into a Zone D, areas of undetermined, but possible, flood hazard (FEMA 1993a). However, based on the location and sandy aquifer, flood hazards are not considered appreciable. No areas of environmental concern have been identified that will impact any of the alternatives under consideration. Both the towns of Falmouth and Bourne were contacted concerning known historical sites in areas under consideration for possible construction. Neither town has identified any historical places that must be taken into consideration when evaluating remedial alternatives.

For remedial alternatives that involve the pumping of groundwater, the impacts of water table mounding and drawdown on area water bodies and vernal pools are a concern. The locations of vernal pools near the FS-28 and FS-29 plumes are shown in Figure 4-1.

Cost: Cost estimates include both total installed costs (TICs) and operation and maintenance (O&M) costs. TICs include costs for equipment, materials, construction related labor, land, site development, utility connections, engineering support, sampling and analysis in support of system design and start-up. O&M costs include operating labor, maintenance and repair materials and labor, energy, process chemicals, disposal of treatment residues, operational sampling and analysis, data management, and administration. O&M costs will be included in life cycle costs using present worth analysis. This analysis (based on EPA guidance) discounts the costs back to present value at a rate of 7 percent per year. (Appendix C also presents costs that have been escalated at a rate of 5 percent per year, which represents the actual amount of future funds expected to be spent after inflation.) It has also been assumed that costs are incurred at the beginning of each year and that the expected useful project life (for cost estimating purposes) is 30 years, unless modeling predicts that a treatment system can be turned off sooner.

Cost estimates are prepared using data available from the RI and are intended to provide an accuracy of between +50 percent and -30 percent. The cost estimates provided are preliminary (Appendix C). More detailed and accurate cost estimates will be developed as the CERCLA process progresses. Cost estimates included in this document are intended for comparative purposes only. They intentionally emphasize comparability (a key factor in the decision making process) versus accuracy.

#### **4.3.3 Modifying Criteria**

There are two modifying criteria: state acceptance and community acceptance. State acceptance evaluates the technical and administrative issues and concerns of the state, specifically the Massachusetts Department of Environmental Protection (DEP). Community acceptance evaluates the issues and concerns that the public may have regarding each of the alternatives. For some alternatives, there may be enough information available to discuss state and community acceptance; however, because this information is not available for most of the alternatives, consideration of



modifying criteria at this time would potentially bias the selection process. In accordance with EPA guidance (EPA 1988), modifying criteria will be evaluated following regulatory comment and public response to this FS and proposed plans for the FS-28 and FS-29 plumes. State and community acceptance will be addressed when a final decision is being made and the Record of Decision is being prepared. Alternatives will not be evaluated against modifying criteria in this FS.

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## 5.0 FS-28 PLUME

### 5.1 DEVELOPMENT AND SCREENING OF ALTERNATIVES

#### 5.1.1 Development of Alternatives

In addition to numerous investigative and monitoring activities, six primary actions have been taken by the Air Force as part of time-critical and non-time-critical removal actions to protect human health and the environment from contamination associated with the FS-28 plume:

- A wellhead protection system was added to the town of Falmouth's Coonamessett Water Supply Well (CWSW).
- Residents in the vicinity of the plume have been connected to town water.
- An extraction, treatment, and discharge (ETD) system (the EW-1 treatment system) was constructed to capture the bulk of plume contaminants.
- The ETD system was modified to include a shallow well-point extraction system located in the bogs south of extraction well EW-1.
- Systems have been put into place that provide agricultural users with clean water.
- Berms and sheet piles were constructed to separate the river from neighboring cranberry bogs and piping was installed to provide these bogs with uncontaminated water.

Treatment system influent and sentinel wells (69MW1279A/B/C) upgradient of the CWSW are monitored for the presence of EDB on a monthly basis. As of March 18, 1999, EDB has not been detected in the supply well influent.<sup>5</sup> Falmouth is considering a combined treatment facility for both the CWSW and the proposed Crooked Pond water supply well (Figure 1-1). Regardless of treatment location, water from the CWSW will continue to be treated to prevent the possibility of EDB entering the public water supply system.

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<sup>5</sup> Monitoring results from the sentinel wells can be summarized as follows. 69MW1279A is screened just below the depth of the CWSW and has consistently had no detectable concentrations of EDB. 69MW1279B is screened approximately 47 feet deeper than the CWSW and has consistently had no

In 1996, the Air Force installed a carbon filtration system at the CWSW to provide wellhead protection. Following installation of this system, area residents were connected to town water to prevent exposure to EDB. Water mains measuring 16,700 feet were installed to connect 125 private residences and one business to the Falmouth public water supply system (AFCEE 1998a). These actions eliminated the primary potential pathway for exposure of area residents to plume contaminants. (The proposed well site at Crooked Pond is cross-gradient to the FS-28 plume and will not be impacted by the plume.)

The EW-1 treatment system has been operational since October 1997. This treatment system was installed as part of a time-critical removal action to capture and treat most of the plume as it crosses Hatchville Road and to reduce contaminant upwelling into the Coonamessett River. The treatment system contains one eight-inch-diameter extraction well (EW-1), two 20,000-pound carbon adsorption vessels, and an aerator located where the plant effluent discharges into the Coonamessett River. From startup through the end of September 1999, the carbon adsorption vessels have treated approximately 655 million gallons of groundwater and removed 5.0 pounds (2.3 kilograms) of EDB from the aquifer.

In the spring of 1999 the EW-1 treatment system was modified (as part of a non-time critical removal action) to include additional plume capture through a shallow well-point extraction system in the bogs south of EW-1. The goal of this modification was to further reduce EDB concentrations in the river system to acceptable levels. This construction also allows treated water to be used for cranberry bog operations. Berms and sheet piles were added in various locations to separate the cranberry bogs from the river.

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*detectable concentrations of EDB. 69MW1279C is screened approximately 87 feet deeper than the CWSW and has consistently had EDB detected at concentrations ranging around 0.01 µg/L, one half of the MMCL.*

Actions taken to date directly address three of the four FS-28 remedial action objectives (Section 2.1). The CWSW wellhead protection system and the residential water connections prevent residential exposure to plume contaminants. Since May 1999, no EDB has been detected in samples collected from the Coonamessett River. By preventing detectable concentrations of EDB from entering the river, the existing treatment system prevents worker and wader contact to unacceptable concentrations of EDB and prevents or reduces the ingestion of fish exposed to water containing unacceptable concentrations of EDB. The remaining remedial action objective calls for the restoration of the aquifer to its beneficial uses within a reasonable time frame. Existing actions (presented as Alternative 3) and more aggressive treatment (Alternatives 4 through 6) are being evaluated in light of this objective.

Seven remedial alternatives for the plume as a whole include the following:

1. No remedial action with long-term monitoring.
2. Continue operation of the EW-1 extraction, treatment, and discharge system, including continued operation and maintenance of the wellhead protection system for the Falmouth Coonamessett Water Supply Well (CWSW) (Figure 1-1). Operation of the shallow well-points would be discontinued under this alternative.
3. Modify the existing EW-1 extraction, treatment and discharge system to include a shallow well-point extraction system in the bogs south of EW-1 in order to reduce EDB concentrations in the river system to acceptable concentrations.<sup>6</sup> Provide an alternate supply of water for cranberry bog operations. Use berms to prevent EDB contaminated water from contacting productive bogs.
4. Construct an ETR system north of Coonamessett Pond in order to reduce the time it will take the aquifer to be restored and to prevent contaminants from migrating under the pond. This alternative includes continued operation of the existing treatment systems as described in the third item in this list.
5. Construct an ETR system immediately north of the western arm of Coonamessett Pond in order to reduce the time it will take the aquifer to be restored and to prevent contaminants in the northwestern portion of the plume from migrating under the pond. This alternative includes continued operation of existing treatment systems as described in the third item in this list.

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<sup>6</sup> The system has been modified to include facilities for the additional extraction mentioned here.

6. Construct an ETR system in the area of Coonamessett Circle (Figure 1-2) in order to reduce the time it will take the aquifer to be restored and to prevent contaminants in the northwestern portion of the plume from migrating under the pond. This alternative includes continued operation of existing treatment systems as described in the third item in this list.
7. Construct an ETD system in Souza Conservation Area (immediately south of the western arm of Coonamessett Pond) in order to reduce the time it will take the aquifer to be restored. This alternative includes continued operation of existing treatment systems as described in the third item in this list.

### **5.1.2 Screening of Alternatives**

#### **5.1.2.1 Alternative 1: No Remedial Action with Long-Term Monitoring**

This alternative would continue to monitor the location and concentrations of plume contaminants, but it would not entail action to prevent exposure or remove contaminants. Under this alternative, existing treatment systems—including EW-1, the shallow well-points, and the CWSW wellhead protection system—would be shut down. The berms and sheet piles that separate the Coonamessett River from neighboring cranberry bogs would not be maintained. (Existing connections to municipal drinking water supplies provided in response to the FS-28 plume would remain unaffected by this alternative.) This alternative would not reduce the risks posed by the FS-28 plume. It could be implemented easily from a technical sense, but administrative approval is unlikely. Compared to the other alternatives presented, this one has lower costs. This alternative will receive detailed analysis for a baseline comparison to other alternatives in accordance with § 300.430(e)(3) of the National Contingency Plan (NCP).

#### **5.1.2.2 Alternative 2: Continued Operation of EW-1 and the CWSW Wellhead Protection System Only**

With this alternative, the EW-1 treatment system and CWSW wellhead treatment systems would continue to operate, as would the monitoring of the treatment systems and the plume itself. Extraction of groundwater by the existing 204 shallow well-points would be discontinued. This alternative would help minimize risks.

particularly long-term risks created by FS-28 plume contaminants. The EW-1 treatment system is well positioned to eventually reduce the amount of contaminant mass present in the aquifer, while the wellhead treatment system will help to ensure that the Falmouth public water supply remains safe. However, the risks posed by the contamination downgradient of the EW-1 treatment system are not addressed by this alternative, nor does this alternative address the risks posed by contamination potentially passing east of the EW-1 capture zone. This alternative would be easily implemented and is slightly less expensive than Alternative 3. However, the small reduction in cost (versus Alternative 3) does not justify the substantial reduction in the efficiency of the system at obtaining the remedial action objectives. This alternative will not receive detailed analysis because it was made obsolete by the implementation of the shallow well-point extraction system as part of the non-time critical removal action.

#### **5.1.2.3 Alternative 3: Continued Treatment System Operations**

This alternative combines the remedial actions to be taken under Alternative 2 with the extraction of additional groundwater from the 204 shallow wells located downgradient of EW-1, treatment of this water at the existing EW-1 treatment system, surface water discharge of the treated water, and berms to isolate cranberry bogs from the river. The existing system allows treated water to be used to flood the cranberry bogs. Compared to Alternative 2, this alternative provides additional risk reduction, particularly for the short-term. Construction aspects of this alternative have been implemented, and the systems are currently operational. Costs for this alternative are slightly higher than those of Alternative 2. This alternative will receive detailed analysis.

#### **5.1.2.4 Alternatives for Additional Treatment and Siting Considerations**

The existing treatment system is well situated to contain FS-28 plume contaminants, but it may be desirable to pursue additional treatment to speed aquifer restoration. If additional treatment is undertaken, it is likely to have a significant impact on local

residents and the environment. The location of the treatment system must be carefully chosen to minimize the time it takes for the aquifer to be restored and at the same time minimize neighborhood and environmental impact.

To understand what additional treatment can and cannot accomplish, it is necessary to understand the capacities and limitations of the existing EW-1 and shallow well-point extraction and treatment system. The naturally-converging flow system containing the FS-28 plume is dominated by the Coonamessett River and affected to a lesser extent by Coonamessett Pond. Although other plumes within the SWOU are increasing in volume as they move downgradient, the converging flow field caused by the river narrows the FS-28 plume as it travels downgradient. The existing treatment system (Alternative 3) is well positioned to not only capture the highest concentrations of contaminants within the next several years (Figure 1-3), but also to take advantage of the converging flow field that will continue to draw plume contaminants toward the extraction well. Because this system appears to be functioning well as a containment system, all measurable concentrations of EDB further upgradient are likely to be captured by the existing system. In other words, additional upgradient treatment (as proposed in Alternatives 4, 5, 6, and 7) will not increase the mass of contaminants ultimately captured. If the existing system proves ineffective as a containment system, the most cost effective option to achieve containment would be to modify the existing system, perhaps through changes in flow rates. On the other hand, the existing system captures the contamination just before it would discharge into the Coonamessett River. It does little to reduce the time until the aquifer is restored. Only additional upgradient treatment can shorten the time until the aquifer is restored.

For additional treatment, extraction could take place north of Route 151, between Route 151 and the western arm of Coonamessett Pond, or south of the western arm of Coonamessett Pond. Figure 5-1 presents an estimate of the distribution of EDB by mass in these three areas based on data collected in late 1996 and early 1997 and a few more recent samples collected from monitoring wells near extraction well EW-1.



Extraction at the ideal location (ignoring all factors that do not impact on contaminant fate and transport) could cut the time to achieve aquifer restoration in half. Advective flow modeling indicates that this ideal location is near the western arm of Coonamessett Pond. As extraction locations are moved further north or south of this area, the time until restoration is achieved will increase.

Extraction North of Route 151. North of Route 151, the FS-28 plume is vertically and laterally discontinuous, and because little of the plume is upgradient, extraction north of Route 151 will do little to reduce the time required until the aquifer restoration is achieved. If system operation were to begin immediately, the time until aquifer restoration is achieved would be reduced by no more than 19 percent according to flow calculations. With extraction occurring at both EW-1 and north of Route 151, the time until aquifer restoration is achieved will be controlled by the advective flow time required for contaminants located just south of the northern capture zone to reach EW-1. The useful life of a northern extraction system would be limited because of the small volume of contaminated water north of Route 151, and because uncontaminated water is flushing the contaminated water further south. Extraction north of Route 151 would also capture water with very low concentrations of EDB. EDB concentrations at the trailing edge of the FS-28 plume are less than 0.1 µg/L and generally close to the detection limit of 0.005 µg/L. Treating water with such low concentrations would have little effect on reducing plume mass. An extraction well fence located north of Route 151 (the trailing edge of the plume) is not appropriate for extracting plume contaminants and, therefore, is not considered further.

Extraction between Route 151 and the Western Arm of Coonamessett Pond. Wells in this location could be arranged either parallel or perpendicular to the axis of the plume. The width of the plume north of Coonamessett Pond's western arm makes axial extraction impractical. Evaluation of extraction systems for plumes of similar thickness and depth indicates that the capture zone of a single extraction well is unlikely to be large enough to capture the entire width of the plume without causing unacceptable ecological impacts. Two or more extraction wells aligned perpendicular

to the axis of the plume would be required to capture the width of the plume. Alternatives with extraction in this location are considered under Alternatives 4, 5, and 6.

Extraction South of the Western Arm of Coonamessett Pond. If extraction were to take place in this area, in order to complement the existing treatment system, it should be as far north as possible.

Extraction in this area could adversely affect the Coonamessett River. Figure 5-2 shows discharge data collected for the past two years from the Coonamessett River at two measuring stations. Station 69SW0058 is located approximately half-way between the river origin at the western arm of Coonamessett Pond and Hatchville Road. Station 69SW0006 is located south of Hatchville Road, where the river enters actively cultivated cranberry bogs near the treatment plant for EW-1. The discharge data show that during 1997, the river did not gain much, if any, flow in the reach between the two measuring stations. In fact, 1998 monitoring showed the river losing water to the aquifer between the two measuring stations, indicated by lower discharge rates at the downstream station (69SW0006) compared with the upstream station (69SW0058). Fish migration in the reach between the bogs and the pond is sometimes restricted because of seasonally low water levels; although, in the past this was mitigated by controlling the pond level at the weir where the river begins. The weir is controlled by the town of Falmouth Shellfish Constable. Groundwater extraction between the western arm of Coonamessett Pond and Hatchville Road could adversely affect this sensitive ecosystem by increasing the drawdown of surface water in the river. Although the river is far more sensitive than the pond, extraction could also potentially lower the pond water level. Groundwater extraction and reinjection would need to be carefully balanced to avoid, if possible, unacceptable changes to the groundwater table. Reinjection of treated water within the potential extraction area could cause plume dispersion or otherwise disrupt the naturally-converging flow field on which downgradient capture is dependent. Dispersion could negatively impact the CWSW influent water quality. Extraction, treatment, and reinjection of groundwater in this area would reduce the EDB concentration of EW-1 influent.

There are several possible advantages of extracting water in this area. Extraction in this area could significantly reduce the time required until the aquifer is restored. This would reduce the time that the existing FS-28 treatment systems would remain operational. In addition, it may be possible to discontinue operation of the CWSW wellhead protection system earlier than would otherwise be possible. Extraction in this location may provide additional protection for the CWSW by pulling contaminants deeper, away from the supply well.

Additional flow to the Coonamessett River may be advantageous to some fish species. This benefit would be temporary. The ecosystem within the river would adapt to the increased flow and could be damaged when flows are eventually restored to their natural state. Extraction south of Coonamessett Pond is considered in Alternative 7.

#### **5.1.2.5 Alternative 4: Continued Remedial Operations with Capture North of Coonamessett Pond**

This alternative combines all remedial actions included in Alternative 3, as well as aggressive additional extraction, treatment, and reinjection north of Coonamessett Pond. The purpose of this additional treatment would be to reduce the time required to restore the aquifer and to prevent contaminants from migrating under Coonamessett Pond. Two extraction well fences would be constructed (Figure 5-3). The first, located just north of the western arm of Coonamessett Pond, would include approximately 10 extraction wells. The goal of this fence would be to hydraulically capture the western portion of the plume and would provide additional protection for the CWSW. The second fence, located directly north of the main body of Coonamessett Pond, would provide additional extraction and reinjection in order to prevent contamination further to the east from delaying achievement of the aquifer restoration remedial action objective. Approximately 10 more extraction wells would be needed for this fence. (The estimate of the required spacing between wells is based on the spacing used successfully at the leading edge of the FS-12 treatment system, near Snake Pond. The plumes lie in the same aquifer, at similar depths and

have similar contaminants and hydraulic characteristics.) Approximately 600 gpm of extraction capacity would be required north of the pond. Treatment would include granular-activated carbon, and discharge would be in a series of reinjection wells. Under this alternative, institutional controls would remain in place until concentrations of contaminants of concern are below drinking water standards.

This alternative would speed aquifer restoration (by approximately 4 years) and provide additional protection for the CWSW. However the additional actions taken under this alternative provide little additional effectiveness in terms of practical risk reduction. This conclusion is based on four factors : (1) due to converging flow, the existing treatment system effectively captures the plume; (2) the low levels of contaminants that would be removed by additional treatment are being flushed from the aquifer by natural processes; (3) residences located above the plume are connected to municipal water supplies and are unlikely to be exposed to measurable levels of contaminants; and (4) the CWSW has an existing carbon adsorption filter system and is unlikely to encounter contaminants of concern in its influent.

Although this alternative is technically feasible, it may not be administratively feasible. Implementation would involve extensive construction in a neighborhood that has strongly expressed disapproval of remedial construction within its boundaries. The large scale of construction activities makes this an expensive alternative to implement. Preliminary cost estimates indicate that the life cycle costs for this alternative would be approximately four times as high as Alternative 3. Because of a lack of effective risk reduction, difficulties in implementation, and high cost, this alternative will not be considered during detailed development and analysis of alternatives.

#### **5.1.2.6 Alternative 5: Continued Remedial Operations with Capture and Containment Immediately North of the Western Arm of Coonamessett Pond**

This alternative combines all remedial actions included in Alternative 3, as well as additional extraction, treatment, and reinjection north of the western arm of

Coonamessett Pond. This alternative is essentially Alternative 4 without the extraction and reinjection well fences north of the main body of Coonamessett Pond. The purpose of the additional treatment would be to reduce the time required to restore the aquifer and to prevent contaminants from migrating under Coonamessett Pond. An extraction well fence would be constructed just north of the western arm of Coonamessett Pond (Figure 5-4). The fence would consist of approximately 10 extraction wells. This system would hydraulically capture the western portion of the plume and would provide additional protection for the CWSW. Approximately 400 gpm of extraction capacity would be required north of the pond. Treatment would include granular-activated carbon; discharge would be through a series of reinjection wells. Under this alternative, institutional controls would remain in place until concentrations of contaminants of concern are below cleanup standards.

This alternative would speed aquifer restoration and provide additional protection for the CWSW. This alternative shares many of the disadvantages of Alternative 4. The additional actions taken under this alternative provide little additional effectiveness in terms of practical risk reduction, and it may not be administratively feasible. Implementation would involve extensive construction in a neighborhood that has strongly expressed its disapproval of remedial construction within its boundaries. The large scale of construction activities makes this an expensive alternative to implement. Preliminary cost estimates indicate that the life cycle costs for this alternative would be approximately three times as high as Alternative 3. Because of a lack of effective risk reduction, difficulties in implementation, and high cost, this alternative will not be considered during detailed development and analysis of alternatives.

#### **5.1.2.7 Alternative 6: Continued Remedial Operations with Capture North of the Western Arm of Coonamessett Pond**

This alternative includes all of the actions described under Alternative 3. In addition, an extraction system would be constructed along Coonamessett Circle (Figure 5-5). Extracted water would be treated with granular-activated carbon and reinjected

downgradient of the extraction wells. The modeled pumping rate for this system was 600 gpm. Under this alternative, institutional controls would remain in place until concentrations of contaminants of concern are below cleanup standards.

This alternative can remove EDB from the aquifer and minimize future risk. This alternative may be effective at reducing the time until the aquifer is restored.

This alternative relies on proven technologies demonstrated at MMR that are technically implementable. There may be administrative difficulties in implementing this alternative, specifically in obtaining access for drilling and construction. However, the construction activities involved in this alternative are substantially less than those described in Alternatives 4 or 5. This reduced scope may reduce the difficulty of obtaining access permission.

This alternative requires extensive additional data acquisition, construction, operations, and maintenance expenses. Modeling indicates that this alternative would shorten restoration time from approximately 18 years under existing conditions to approximately 11 years. Despite a shorter life cycle than Alternative 3, the cost for this alternative will be higher. Modeling indicates that this alternative will be more effective at speeding aquifer restoration and cost less than Alternatives 4 or 5. Because this alternative directly addresses the remedial action objective of aquifer restoration, it will be retained for detailed analysis.

#### **5.1.2.8 Alternative 7: Continued Remedial Operations with Additional Extraction and Treatment in the Souza Conservation Area**

Under this alternative an additional extraction, treatment and discharge system would be constructed in the Souza Conservation Area, just south of the western arm of Coonamessett Pond. The modeled system contained three extraction wells each pumping 200 gpm (Figure 5-6). Water would be treated with granular-activated carbon and discharged to Coonamessett Pond and River. All of the remedial actions included under Alternative 3 would also be included in this alternative. Under this

alternative, institutional controls would remain in place until concentrations of contaminants of concern are below cleanup standards.

This alternative would be effective at speeding aquifer restoration. Under this alternative EDB concentrations greater than the MMCL would remain in the aquifer for approximately nine years. Although this system would not be able to contain the plume north of the CWSW, it would provide additional protection for the well. This protection would be provided by extracting water deeper than the supply well and thus pulling the plume down and away from the CWSW screen location within the aquifer.

There are no major technical obstacles to prevent the implementation of this alternative. Implementation of this alternative would have significant ecological impacts to the Coonamessett River. Construction within the conservation area would also have significant environmental impacts. These impacts may make it difficult to obtain access permission required to implement this alternative.

Life cycle costs for this alternative are significantly more than for Alternative 3, and comparable to Alternative 6. This alternative will be retained for detailed analysis.

## **5.2 DETAILED DESCRIPTION AND EVALUATION OF ALTERNATIVES**

### **5.2.1 Alternative 1: No Remedial Action with Long-Term Monitoring**

This alternative would implement long-term monitoring through sampling and analysis of the FS-28 plume. In accordance with EPA guidance, this alternative does not include any active measures to remove, destroy or immobilize contamination; therefore, neither the FS-28 treatment system (including extraction well EW-1 and the 204 shallow well-point system) nor the CWSW wellhead protection system would remain in operation. Existing berms and sheet piles would not be maintained; nearby agricultural users could no longer rely on treatment system effluent as a source of uncontaminated water. Under this alternative, no steps would be taken to prevent human exposure to contaminated groundwater or surface water. Existing residential

water supply connections would be left in place under this alternative. This alternative would serve as a baseline for comparison with other alternatives in accordance with §300.430(e)(3) of the NCP.

Although no active remedial action is included in this alternative, natural processes will continue to affect the FS-28 plume (AFCEE 1999c). The plume will continue to move downgradient and decrease in volume. Discharge of contaminated water into the Coonamessett River will be the primary natural process affecting plume mass. Once contaminated groundwater discharges into the river system, dilution in surface water decreases concentrations. EDB has a Henry's Law Constant of  $7.06 \times 10^{-4}$  atm·m<sup>3</sup>/mol, suggesting that it will volatilize moderately quickly from the river. Under normal conditions, the volatilization half-life from a typical river is about one day (EPA 1998c). Under current conditions, EDB in the Coonamessett River generally dilutes, volatilizes, or degrades below detectable levels by the time the river passes beneath Route 28 (AFCEE 1998e) approximately 7300 feet south of the current downgradient extent of the plume.

Natural attenuation in groundwater is slower than in surface water. Dispersion reduces the maximum concentration of EDB, but could also increase the volume of groundwater impacted by the plume. EDB is subject to abiotic degradation by hydrolysis that could result in a half-life of approximately 2.2 years (Howard et al. 1991). Restoration times for the FS-28 plume are driven by flow times to extraction or discharge locations.

If implemented, this alternative could continue to expose receptors in the Coonamessett River to EDB contamination upwelling with groundwater.

Under Alternative 1, the monitoring program will consist of sampling monitoring wells downgradient, to either side, and within the body of the plume. Monitoring activities for this alternative would be essentially the same as those described in the engineering evaluation and cost analysis (EE/CA) (AFCEE 1998a). However, without operating treatment systems, it is unlikely that sampling could be curtailed



until after the trailing edge of the FS-28 plume naturally flushed out into the Coonamessett River, which would take about 18 years according to flow calculations. It is estimated that monitoring would consist of sampling approximately 16 different monitoring wells quarterly for EDB. In addition to monitoring the plume itself, it would be necessary to monitor the influent to the CWSW and three sentinel wells upgradient from the well site. Samples at these four locations would be taken monthly and analyzed for EDB. (Monitoring details presented were used for cost estimating. Actual monitoring requirements would be developed during remedial design.)

Surface water and irrigation wells would also be sampled. It is estimated that 27 surface water samples would be required each month for the next 18 years. Approximately 38 irrigation well samples would be required annually. Both surface water and irrigation well samples would be analyzed for EDB. All samples would be obtained and analyzed in accordance with the *Quality Program Plan* (AFCEE 1998g). Ecological sampling, used to monitor the ecological impact of treatment systems, would not be required for this alternative.

Table 5-1 presents a summary of the evaluation for Alternative 1 according to CERCLA evaluation criteria and the remedial alternative evaluation system presented in Section 4.3. A discussion of the evaluation follows.

**Table 5-1  
Evaluation of Alternative 1: FS-28 Plume**

<b>Evaluation Criteria</b>	<b>Value</b>
Overall Protection of Human Health and the Environment	No
Compliance with ARARs	No
Long-term Effectiveness and Permanence	1
Reduction in Toxicity, Mobility, and Volume Through Treatment	0
Short-term Effectiveness	1
Implementability	5
Cost (present value, millions of dollars)	\$3.4

Overall Protection of Human Health and the Environment. This alternative fails to take adequate steps to protect human health and the environment from exposure to EDB in the FS-28 plume since the CWSW would no longer be allowed to operate without the wellhead treatment system. The DEP has prohibited the use of the CWSW without the wellhead treatment for EDB. If this alternative is implemented, the town of Falmouth may experience severe water shortages. Public health and welfare may be compromised during an event such as a major fire or during the summer tourist season. Cranberry bog workers, children and adults who wade in the Coonamessett River and fish-eaters may be exposed to unacceptable levels of EDB.

The SWOU RI determined that relatively high concentrations of EDB (18 µg/L) are present in the groundwater upgradient of the area where the plume discharges to the surface. If no remedial action is taken, concentrations of EDB in the surface water may increase significantly. This alternative takes no action to reduce the risks that EDB and lead pose to area residents and fails to adequately protect human health and the environment.

Compliance with ARARs. With no remedial action, levels of EDB and lead in the groundwater and surface water will continue to exceed MCLs and MMCLs. Under the National Contingency Plan, MCLs are relevant and appropriate to groundwater that is a potential drinking water source. The same status exists for MMCLs under the Massachusetts Contingency Plan. There is a small probability that water supplied by the CWSW in the future could have contaminant concentrations in excess of the MCLs set in the Safe Drinking Water Act (40 CFR 141). The Coonamessett River is not currently a source of drinking water (Appendix A, Tables 1 through 3).

Long-term Effectiveness and Permanence. This alternative takes no action to remove or destroy FS-28 contamination. Neither 100 percent capture of plume contaminants nor treatment to background would be accomplished. Natural attenuation will eventually remove or degrade contamination present in the plume, but not in an acceptable time frame. Implementation of this alternative would likely result in the

closure of the CWSW. The continued presence of FS-28 plume contaminants in the groundwater and surface water can have negative socioeconomic impacts for area residents.

Reduction of Toxicity, Mobility, or Volume Through Treatment. This alternative will not treat, remove, or immobilize contamination. Consequently, this alternative does not reduce the toxicity, mobility, or volume of contamination. The mass of groundwater contaminants will be reduced over time, primarily through discharge into the Coonamessett River. This alternative will not satisfy the regulatory preference for treatment as a principal element of a remedial action.

Short-term Effectiveness. This alternative does not pose unacceptable risks to workers engaged in monitoring activities. The community could be exposed to unacceptable levels of EDB through the Falmouth public water supply system and through the Coonamessett River. Aquatic species in the river could be exposed to unacceptable levels of lead (AFCEE 1999c). Flow calculations indicate that the plume will continue to discharge into the Coonamessett River for approximately 18 years.

Implementability. There are no technical difficulties associated with the no-remedial action alternative, nor are administrative difficulties anticipated with sampling surface water and existing monitoring and irrigation wells.

Cost. The extensive monitoring efforts included in this alternative will cost approximately \$270,000 to establish a baseline. Annual costs will be approximately \$340,000 for each of the next 18 years. The present value of the life cycle costs for this alternative are approximately \$3,400,000. There is uncertainty in the estimated time for natural processes to flush contaminants from the aquifer. If more time is required, costs can be expected to exceed those presented.

### 5.2.2 Alternative 3: Continued Treatment System Operations

This alternative already provides an alternate water supply for the cranberry bogs along the Coonamessett River, berms to separate the cranberry bogs from the river, and expanded extraction and treatment of groundwater (through the shallow well-point extraction system) along with the existing extraction system provided by well EW-1. This alternative would include continued operation of the EW-1 treatment system, the wellhead treatment system for the CWSW, and the 204 shallow well-point extraction system along with appropriate monitoring activities. Existing berms and sheet piles that separate the Coonamessett River and neighboring cranberry bogs would be maintained under this alternative. Institutional controls are also included and would remain in place until plume contaminant of concern concentrations are below cleanup standards. Cleanup standards are defined as the most stringent of MCLs, MMCLs, or risk-based standards (if no MCLs or MMCLs are available). Key treatment components of Alternative 3 are shown on Figure 5-7. Treated water from the EW-1 and shallow well-point treatment system would be used, if necessary, to avoid the use of potentially contaminated river water for cranberry operations in the upper bogs.

The evaluation of this alternative, according to CERCLA criteria, is summarized in Table 5-2. A discussion of the evaluation follows.

**Table 5-2**  
**Evaluation of Alternative 3: FS-28 Plume**

<b>Evaluation Criteria</b>	<b>Value</b>
Overall Protection of Human Health and the Environment	Yes
Compliance with ARARs	Yes
Long-term Effectiveness and Permanence	5
Reduction in Toxicity, Mobility and Volume Through Treatment	4
Short-term Effectiveness	4
Implementability	4
Cost (present value, millions of dollars)	\$7.1

Overall Protection of Human Health and the Environment. Groundwater associated with the FS-28 plume poses potentially unacceptable risks to area residents. These potential risks only pose a danger to human health when complete exposure pathways exist. Most residents of the area surrounding the FS-28 plume are supplied with public water. No known completed pathways exist between the plume contaminants and the area residents. There are a handful of residents who use area groundwater from private wells and who could be potentially exposed, although these wells are generally much more shallow than the plume contamination. EDB was detected in two private wells in the spring of 1997. Since that time EDB has not been detected in any private wells in the vicinity of the FS-28 plume. Except for surface water bodies, no known completed exposure pathway currently exists. This alternative includes the current EW-1 and shallow well-point treatment system combined with additional shallow well-point extraction and the natural flushing action of the Coonamessett River. Each of these would remove contaminants from the aquifer and help to minimize risk. Berms and an alternate water supply would minimize the possibility that consumption of EDB-contaminated cranberries could become a completed exposure pathway. Under this alternative, institutional controls would remain in place until concentrations of contaminants of concern are below cleanup standards.

Despite the aggressive treatment actions that would be pursued under this alternative, a small portion of plume contaminants would remain uncaptured. This EDB could eventually discharge into the Coonamessett River. Since May 1999, EDB has not been detected in the surface water of the Coonamessett River or the surrounding bogs. This is believed to be attributable to the effectiveness of the time-critical and non-time-critical removal actions implemented by AFCEE. It is believed any EDB that discharges into the river in the future will be at low concentrations. This alternative actively and aggressively seeks to minimize risks posed by EDB plume contaminants. It is adequately protective of human health and the environment.

Compliance with ARARs. This alternative complies with the chemical-specific groundwater ARARs because the MMCL of 0.02 µg/L for EDB will be met in

approximately 18 years. If operated according to design, effluent from the FS-28 treatment system will continue to meet all ARARs. The CWSW wellhead treatment will help to ensure that Safe Drinking Water Standards continue to be met during the course of the remedial action (Appendix A, Tables 1 through 3).

Long-Term Effectiveness and Permanence. This alternative actively removes contamination from the groundwater near its discharge point to the Coonamessett River. Because of the highly soluble nature of EDB and the low fraction of organic carbon in the aquifer matrix, there is little potential for significant sorption or desorption. This alternative satisfies CERCLA's preference for remedial actions that employ treatment that permanently and significantly reduces the volume of contaminants as a principle element.

Under this alternative, the current EW-1 and shallow well-point treatment system would capture the portion of the plume upgradient of EW-1, with the possible exception of some contamination that may pass too far to the east. This water and most of the water downgradient of EW-1 would be captured by shallow well-points. Captured contamination would be treated to obtain background levels. It is possible that a portion of the extreme leading edge of the plume (contamination in the vicinity of where monitoring well 69MW1295 is screened) may evade capture by both extraction systems (Figure 5-7). EDB contamination downgradient of the shallow well-point capture zone would not be captured.

Since May 1999, no EDB has been detected in the surface water in the cranberry bogs surrounding the Coonamessett River. This appears to be due to the effectiveness of EW-1 and the shallow well-points which capture EDB-contaminated groundwater before it upwells into the bogs. Since the risks to waders and fish consumers were based on EDB in surface water, these risks appear to have been mitigated by the interim actions.

Based on samples from four drive-points, 15 borehole water samples, and three monitoring wells, the mass of the EDB that will elude capture has been estimated at

approximately 0.038 kilograms (kgs). This amounts to about 0.3 percent of the total mass of EDB in the plume. The uncaptured mass equals approximately 4 percent of the mass that the FS-28 treatment system captured during its first year of operation (Figure 5-8). This EDB is in an area of strong groundwater convergence, meaning that the flow paths for groundwater from both sides of the Coonamessett River come together as the groundwater rises towards the river bottom. The leading edge of the finger of the contamination in question will accelerate as it rises and mixes with the surrounding groundwater. Because the trailing edge of this contamination is more distant from the point of convergence, the acceleration of this portion of the contamination will be less, and the entire volume of uncaptured contamination will tend to elongate. As EDB-contaminated water enters the river, it will rapidly mix with the clean river water, including treated water from the FS-28 treatment system, and become diluted. However, the possibility exists that detectable concentrations from this portion of the FS-28 plume could reach the Coonamessett River. This alternative does not propose treatment for this uncaptured volume of contamination.

This alternative would capture approximately 99.7 percent of EDB in the FS-28 plume. Captured groundwater would be treated to non-detectable concentrations of EDB. When combined with natural processes, active components of this alternative will reduce contaminant concentrations in the aquifer to background levels. No unacceptable human health or environmental risks from uncaptured contamination are anticipated. The CWSW wellhead treatment system would continue to operate, ensuring a continued safe public water supply. This alternative minimizes negative socioeconomic impacts from surface water contamination. Negative socioeconomic impacts from the continued presence of groundwater contamination may continue to occur.

Reduction of Toxicity, Mobility, or Volume Through Treatment. The mass of contamination present in the FS-28 plume will be greatly reduced under this alternative. This alternative will result in a greater percent of plume capture than Alternative 1. Some contamination may escape capture by active treatment, but it is

believed that EDB concentrations will be non-detectable in the Coonamessett River because the small volume of contaminated water will probably discharge to the river for a relatively long period of time, and this contamination will probably mix with the clean river water almost instantly.

Short-Term Effectiveness. This alternative would be carried out in a manner that will be protective of both the community and site workers. As with any plan requiring operations and maintenance within a wetland, particular care will be required to ensure that the environment is adequately protected.

Like Alternative 1, it is estimated that at least 18 years will be required to achieve remedial objectives under Alternative 3. If a single flush of clean water is not sufficient to remove the EDB, longer treatment times would be required. If the effects of hydrolysis are substantial, shorter treatment times would be required. The FS-28 treatment system and extraction taking place in the Coonamessett River cranberry bogs will do little to speed the transport of contamination currently in the northern portion of the plume. This alternative will remove the volumes of groundwater with the highest levels of contamination over the next five years. During that same period, most of the contamination downgradient of the extraction well will be captured and treated. A small portion of the plume will continue to discharge into the Coonamessett River.

The shallow well-point extraction system came on-line in April 1999. Samples from the 27 surface water monitoring locations collected in May and June 1999 contained no detectable concentrations of EDB, suggesting that the system is effective at capturing the contamination before it discharges to the river.

Implementability. This alternative relies exclusively on proven technologies, including granular-activated carbon adsorption, well and well-point groundwater extraction, and earthen berms. Little or no difficulty has occurred in obtaining the personnel, materials, and equipment required to implement this alternative. Construction aspects of this alternative have been completed. Because the plume is



composed of fuel components (as opposed to hazardous waste as defined under CERCLA), remediation will not qualify for CERCLA's exemption from permitting. All necessary permits needed for implementation of the treatment systems in place have already been obtained.

Cost. The annual cost for operations and maintenance of this alternative is \$680,000. The present value of this alternative is estimated to be \$7,100,000. If treatment periods longer than 18 years are required, higher costs will result. Costs presented above do not include the costs previously incurred for design and construction of the EW-1 treatment system (\$670,000) or the CWSW wellhead treatment system (\$470,000). The shallow well-point system and berm construction costs (\$2,650,000) are not included either. (Sunk costs are presented for informational purposes only and are not taken into consideration in the decision making process.)

### **5.2.3 Alternative 6: Continued Remedial Operations with Capture North of the Western Arm of Coonamessett Pond**

Alternative 6 combines hydraulic containment of the FS-28 plume with additional capture within the body of the plume. This additional capture would reduce the time required to reach aquifer restoration. This alternative would also provide additional protection for the CWSW and includes institutional controls, which would remain in place until the concentration of the plume contaminant of concern is below cleanup standards. Cleanup standards are defined as the most stringent of MCLs, MMCLs, or risk-based standards (if no MCLs or MMCLs are available).

Alternative 6 includes all actions already in place under Alternative 3, specifically:

- continued operation of EW-1, the shallow well-point extraction system, and the existing treatment system,
- continued operation of the CWSW wellhead treatment system,
- alternate water supply for cranberry bog operations, if necessary, and
- berms to separate some cranberry bogs from the river.

This alternative would also provide additional extraction of contaminated groundwater just north of the western arm of Coonamessett Pond. ReInjection wells, as opposed to less expensive infiltration galleries, would be required to minimize the flow of treatment system effluent through the pond. It is estimated that approximately five extraction wells and three reinjection wells (installed generally around Coonamessett Circle just north of the western arm of Coonamessett Pond) would be required. If implemented, additional data gathering and design would take place before actual well locations are selected. Hypothetical well locations were chosen for the purpose of modeling and evaluation (Figure 5-5).

The treatment system would be designed to treat approximately 600 gpm through a pair of carbon adsorbers. Relatively low metals concentrations from area wells indicates that pretreatment will probably not be required (Table 5-3). Depending on the treatment plant location, this treatment system would require approximately 5,000 feet of extraction pipeline and approximately 3,600 feet of reinjection pipeline. For costing purposes it was assumed that the treatment plant would be located in undeveloped land to the west of the Lochstead development. Pipelines would travel beside existing roads as much as possible. The treatment plant would be offset from public roads to minimize visual impact.

**Table 5-3**  
**Alternative 6: Expected Treatment System Influent**

<b>Constituent</b>	<b>Short-term Influent Concentration</b>	<b>Long-term Influent Concentration</b>
EDB	0.60	0.20
Total Iron	200	100
Total Manganese	65	32

All values in micrograms per liter  
EDB concentrations based on advective flow modeling.  
Short-term EDB influent concentration based on the first seven months of operation. Long-term EDB influent concentration based on the first 5.4 years of operation. The influent concentration at the end of this period (4.8 to 5.4 years) was modeled at 0.03 µg/L.

This alternative will require a project execution plan and a design report. As part of detailed design of the ETR system, additional data would need to be obtained. Data-gap wells would be used as much as possible for performance monitoring evaluation of the ETR system. All samples would be analyzed for EDB.

A sampling and analysis plan and a system performance and ecological impact monitoring plan would also be required. Operational monitoring would require monthly samples of the influent, the water between the carbon adsorbers, and the effluent. Samples would be analyzed for EDB in accordance with the *Quality Program Plan* (AFCEE 1998g). (Monitoring details presented were used for cost estimating. Actual monitoring requirements would be developed during remedial design.) Sampling and analysis to demonstrate hydraulic performance and no adverse ecological impact would be performed in accordance with standards defined during remedial design. Thorough site reviews would be required every five years as long as contamination above regulatory concentrations remained in the aquifer.

Table 5-4 presents a summary of the evaluation of Alternative 6 according to CERCLA criteria. A discussion of the evaluation follows.

**Table 5-4**  
**Evaluation of Alternative 6: FS-28 Plume**

<b>Evaluation Criteria</b>	<b>Value</b>
Overall Protection of Human Health and the Environment	Yes
Compliance with ARARs	Yes
Long-Term Effectiveness and Permanence	5
Reduction in Toxicity, Mobility and Volume Through Treatment	4
Short-Term Effectiveness	4
Implementability	1
Cost (present value, millions of dollars)	\$15

Overall Protection of Human Health and the Environment. This alternative is protective of human health and the environment. Advective flow modeling estimated

that under this alternative, the portion of the plume north of the western arm of Coonamessett Pond would reach drinking water standards in approximately four years. The portion of the plume south of the western arm of Coonamessett Pond would require approximately 11 years to reach drinking water standards.

As with Alternative 3, Alternative 6 fails to capture a small portion of the extreme distal end of the plume downgradient of the bog separation project. The goal of the Coonamessett River bog project is incorporated into this alternative and is feasible.

Compliance with ARARs. This alternative is in full compliance with state and federal ARARs. The MMCL for EDB will be attained in approximately 11 years. The alternative can be implemented in a manner that complies with all location- and action-specific ARARs (Appendix A, Tables 1 through 3).

Long-Term Effectiveness and Permanence. This alternative actively removes contamination from the aquifer. It would capture approximately 99 percent of plume mass and treat captured groundwater so that no detectable EDB concentrations are re-released into the aquifer. When combined with natural processes, active components of this alternative will reduce contaminant concentrations in the aquifer to background levels. No unacceptable human health or ecological impacts from uncaptured contamination are anticipated. It contains measures both to contain the plume and to speed the removal of contaminants from the aquifer. Once removed, recurrence of the contamination is not possible. This alternative could protect the CWSW with both wellhead treatment and accelerated removal of upgradient contaminants from the aquifer. During the period that the northern treatment system remains in operation, a portion of the CWSW influent would be the treatment system effluent. ReInjection under this alternative would cause an estimated 0.7 feet of mounding in the vicinity of the reinjection wells and 0.1 foot of mounding near the CWSW. During active treatment, this alternative could have a negative impact on the quality of life and property values in areas where new construction is conducted.

Reduction of Toxicity, Mobility, or Volume Through Treatment. This alternative will reduce the mass of contaminants present. The highly mobile nature of EDB ensures that significant residuals will not remain after treatment. Some contamination may escape capture by active treatment, but it is believed that EDB concentrations will be non-detectable in the Coonamessett River, due to the assumption that the small volume of contaminated water will discharge to the river over a relatively long period of time, and that this contamination would be mixed with the clean river water almost instantly.

Short-Term Effectiveness. This alternative can be implemented in a manner that is protective of the community and site workers. This alternative is likely to have ecological impacts that may exceed ecological design targets (AFCEE 1998f). In order to prevent an upwelling of plume contaminants, extraction would take place deep in the water column, and treatment system effluent would be reinjected relatively high in the aquifer. This may result in more than 25 percent of the water flux through the pond being reinjected water. Extensive design and modeling efforts will be required to ensure that unacceptable levels of drawdown and mounding do not occur in surface waters. Approximately 11 years will be required before EDB concentrations in the aquifer are reduced below the MMCL. This alternative would speed restoration of the aquifer in the vicinity of the CWSW.

Implementability. This alternative relies on technologies that have been previously demonstrated at MMR. Technically, the implementation of this alternative should not encounter major obstacles, but will rely on sophisticated modeling and engineering.

Obtaining the required access permission to implement this alternative may be a major obstacle. The area where additional treatment facilities would be located is a private, gated community. Previous requests to drill monitoring wells in this area have been met with resistance. Implementation of this alternative will require both extensive drilling and construction efforts. Area residents have specifically requested that remedial construction not be conducted in their community. Because of the

density of existing homes, much of the drilling would necessarily be along residential roads.

Cost. The total installed cost for this alternative is approximately \$8,800,000. Initially, annual operations and maintenance costs would accrue at a rate of \$1,000,000 per year. Annual operations and maintenance costs would decrease substantially once the northern system discontinued operations. The present value for life cycle expenses is approximately \$15,000,000. Costs presented above do not include the costs previously incurred for design and construction of the EW-1 treatment system (\$670,000) or the CWSW well head treatment system (\$470,000). The shallow well-point system and berm construction costs (\$2,650,000) are not included either. (Sunk costs are presented for informational purposes only and are not taken into consideration in the decision making process.)

#### **5.2.4 Alternative 7: Continued Remedial Operations with Additional Extraction and Treatment in the Souza Conservation Area**

Alternative 7 includes extraction and treatment in the Mathew R. Souza Memorial Conservation Area (Figure 5-6). Extraction of groundwater would necessarily take place in relatively close proximity to the CWSW. Treatment would include granular-activated carbon. Treated water would be discharged to both Coonamessett Pond and Coonamessett River. The modeled system treated 600 gpm with the treated water discharged to the pond and the river. This alternative includes all actions presented under Alternative 3. Additional capture included in this alternative would reduce the time required to reach aquifer restoration. In addition, this alternative may provide additional protection for the CWSW and would include institutional controls. Institutional controls would remain in place until the concentrations of the plume contaminant of concern is below cleanup standards. Cleanup standards are defined as the most stringent of MCLs, MMCLs, or risk-based standards (if no MCLs or MMCLs are available).

If implemented, additional data collection and design work would take place before actual extraction well locations are selected. Extraction would take place at approximately three extraction wells. These wells would be located along the southern shoreline of the western arm of Coonamessett Pond. The wells would be spread as much as possible across the width of the plume. This would require that water be piped under the Coonamessett River. Approximately 1900 feet of extraction pipeline would be required.

Treatment would take place through a pair of carbon adsorbers. Relatively low metals concentrations from area wells indicate that pretreatment will probably not be required (Table 5-3).

In the modeled system, 300 gpm were discharged to Coonamessett Pond and 300 gpm were discharged to the Coonamessett River<sup>7</sup>. During actual system operation, system influent would generally remain at the design level, but the distribution of effluent discharge may be adjusted as the water level in the pond and river fluctuates. During periods of low river flow, more water might be discharged to the river to help ensure continued flow throughout the upper reach of the river. During periods of high river flow, more water might be discharged into the pond to minimize erosion of the river banks.

This alternative will require a project execution plan and a design report. As part of the detailed design of the ETD system, additional data would need to be obtained. As far as practical, data-gap wells would also be used for performance monitoring evaluation of the ETD system. All samples would be analyzed for EDB.

A sampling and analysis plan and a system performance and ecological impact monitoring plan would also be required. Operational monitoring would require

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<sup>7</sup> Because river water leaves the regional groundwater flow regime on a time scale much faster than that of the model, discharge to the river is effectively removed from the model.

monthly samples of the plant influent, the water between the carbon adsorbers, and the plant effluent. Plant influent and effluent sampling would be required to meet the requirements of the National Pollution Discharge Elimination System. A Notice of Intent to the local conservation commission and a Chapter 91 permit may also be required. Samples would be analyzed for EDB in accordance with the *Quality Program Plan* (AFCEE 1998g). Sampling and analysis for hydraulic and ecological performance would be performed semiannually for the first two years and annually thereafter. (Monitoring details presented were used for cost estimating. Actual monitoring requirements would be developed during remedial design.) Thorough site reviews would be required every five years as long as contamination above regulatory concentrations remained in the aquifer.

Table 5-5 presents a summary of the evaluation for Alternative 7 according to CERCLA criteria. A discussion of the evaluation follows.

**Table 5-5**  
**Evaluation of Alternative 7: FS-28 Plume**

<b>Evaluation Criteria</b>	<b>Value</b>
Overall Protection of Human Health and the Environment	Yes
Compliance with ARARs	Yes
Long-Term Effectiveness and Permanence	5
Reduction in Toxicity, Mobility and Volume Through Treatment	4
Short-Term Effectiveness	1
Implementability	2
Cost (present value, millions of dollars)	\$12

Overall Protection of Human Health and the Environment. This alternative is protective of human health and the environment. According to advective flow modeling, the portion of the plume north of the western arm of Coonamessett Pond would reach drinking water standards in approximately 9 years. The portion of the plume south of the western arm of Coonamessett Pond would also require



approximately 9 years to be remediated to drinking water standards. The time until the entire plume is remediated to cleanup standards would be reduced by approximately 50 percent under this alternative.

As with Alternative 3, this alternative fails to capture a small portion of the extreme distal end of the plume downgradient of the shallow well-point extraction field. The objectives of the Coonamessett River bog project include the remediation of the distal end of this plume.

Compliance with ARARs. This alternative is in full compliance with state and federal ARARs. The MMCL for EDB will be attained in approximately 9 years. This alternative can be implemented in a manner that complies with all location- and action-specific ARARs (Appendix A, Tables 1 through 3).

Long-Term Effectiveness and Permanence. This alternative actively removes contamination from the aquifer. It would capture approximately 99 percent of plume mass and treat captured groundwater so that no detectable EDB would be re-released into the aquifer. When combined with natural processes, active components of this alternative will reduce contaminant concentrations in the aquifer to background levels. No unacceptable human health or ecological impacts from uncaptured EDB are anticipated. It contains measures both to contain the plume and to speed the removal of contaminants from the aquifer. Once removed, recurrence of the contamination is not possible.

This alternative would protect the CWSW with wellhead treatment. In addition, extraction in the vicinity of the water supply well would take place deeper in the aquifer and would tend to draw plume contaminants deep in the aquifer and away from the CWSW well screen. Extraction to take place under this alternative would draw the water table down approximately 0.6 feet (in addition to drawdown due to existing wells) in the vicinity of the CWSW. Accelerated remediation of the aquifer could reduce the amount of time that the CWSW wellhead protection system would be required. The accelerated cleanup would also reduce the operational life of

treatment systems operating in the southern portion of the plume. Because construction would take place away from existing housing, the negative socioeconomic impacts associated with this alternative would be minimized. Construction and the presence of the treatment system within the conservation area would have a negative impact on the quality of life for area residents who use the area for recreation.

Reduction of Toxicity, Mobility, or Volume Through Treatment. This alternative will reduce the mass of contaminants present. The highly mobile nature of EDB ensures that significant residuals will not remain after treatment. Some contamination may escape capture by active treatment, but it is believed that EDB concentrations will be non-detectable in the Coonamessett River because the small volume of contaminated water will probably discharge to the river over a relatively long period of time, and this contamination would likely mix with the clean river water almost instantly.

Short-Term Effectiveness. This alternative can be implemented in a manner that is protective of the community, site workers, and the environment. Approximately 9 years will be required to meet remedial action objectives.

This alternative will have significant environmental impacts. The Souza Conservation Area is a wooded tract located just south of the western arm of Coonamessett Pond. The Coonamessett River divides the area from north to south. The white pine tree is the dominant species along with a variety of subdominant deciduous trees. The diversity of the ecosystem gives the area particular importance. Monitoring and extraction wells, extraction and reinjection pipelines, and the treatment system itself would be installed within the conservation area. This would require the construction of access roads and clearing of areas for system construction.

In addition to these direct impacts on area habitat, extraction of groundwater and discharge of treated water in this area would have a significant impact on regional groundwater in an ecologically sensitive area. Several of the most pertinent of the

ecological design targets for the MMR Installation Restoration Program are presented in Table 5-6 (AFCEE 1998f).

**Table 5-6  
Ecological Design Targets**

<b>WATER LEVEL CHANGE AND ECOSYSTEM WATER FLUX</b>	
1.	No change in annual hydrogeologic regimes as a result of varied treated groundwater fluxes or discontinuous treatment rates. The general pattern of water level change should be maintained.
2.	Pond water levels should not vary more than 0.5 feet as a result of plume remediation activities.
3.	Vernal pool, bog, and riverine ecosystems water levels should not vary more than 0.2 feet as a result of plume remediation activities.
4.	No more than a 20 percent change in the water flux through a pond ecosystem.
5.	No more than 25 percent of the water flux through a pond ecosystem can be reinjected water from plume remediation systems.
<b>pH, DISSOLVED OXYGEN (DO), AND TEMPERATURE</b>	
1.	If pre-treatment pH, DO, and temperature values for a pond meet current Massachusetts surface water quality criteria, then estimated post-treatment values for these parameters must also meet these criteria. The pH should be measured as a monthly mean throughout the year, DO as the minimum monthly values throughout the year, and temperature as monthly mean during spawning and growing seasons. These criteria apply only for photic zone measures.
2.	If average ambient groundwater values for DO exceed 5 milligrams/liter (mg/L), then groundwater treatment should not cause levels to drop to less than 5 mg/L.

Implementation of this alternative would change the flow regime in this area from a system controlled by gravity and weir boards to an automated system controlled by mechanized pumps and valves. There are both advantages and disadvantages to this change.

As the treatment system was modeled (300 gpm to Coonamessett Pond and 300 gpm to Coonamessett River), several of the ecological design criteria might be violated. Three-hundred gpm (approximately 0.67 cubic feet per second) is more water than currently flows through the Coonamessett River during dry periods (Figure 5-2). Thus, the magnitude of seasonal water level change would be lessened. During periods of high flow, the additional water may erode the banks of the Coonamessett

River. Throughout the year, the additional flow is also likely to change the level of the river by more than 0.2 feet.

Discharge of 300 gpm to Coonamessett Pond may also violate ecological design targets. Previous modeling efforts have indicated that approximately 1500 gpm of water travel through Ashumet Pond, a somewhat larger pond located northeast of Coonamessett Pond. Thus, the modeled discharge has the potential to cause more than 25 percent of the flux through Coonamessett Pond to be system effluent.<sup>8</sup>

Extraction in this area will have an additive effect with existing groundwater table drawdown caused by the CWSW. Water discharged directly to the Coonamessett River is effectively removed from the regional groundwater flow regime. Water that raises the level of Coonamessett Pond so that additional water flows down the Coonamessett River is also effectively removed from the regional groundwater flow regime. This removal results in a local decrease in groundwater elevation.

Some of the ecological impacts of the treatment system may be minimized or even turned into advantages by varying flow rates over time. During periods of low flow, the additional flow in the Coonamessett River may be desirable for some fish species, despite violating one of the ecological design criteria. During periods of high flow, discharge to Coonamessett Pond could be increased to buffer erosion along the river channel, which may also violate ecological design targets.

The temperature of the extracted and treated groundwater can be expected to be generally colder than the water in the river. Aerators may need to be included to ensure that there is sufficient dissolved oxygen in the river.

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<sup>8</sup> Models have significant uncertainty in estimating contaminant flux to surface water bodies. Ecological targets will be considered during remedial design. However, these targets are only goals and several previous projects have gained acceptance from regulatory agencies, the Technical and Review Evaluation Team, and the public without meeting these targets. Appropriate and sufficient ecological monitoring would be required to evaluate the magnitude of impacts.

Because of the significant environmental impacts caused by this alternative, long-term changes may take place in the Coonamessett River. The ecology in the area will adapt to increased river flow throughout the year. Termination of system operations may have unacceptable ecological impacts.

Implementability. This alternative relies on technologies that have been previously utilized at MMR. Technically, the implementation of this alternative should not encounter major obstacles, but will rely on sophisticated modeling and engineering.

Obtaining the required access permission to implement this alternative may be a major obstacle. The area where additional treatment facilities would be located is a town of Falmouth conservation area. Construction in this area is in conflict with the intended use of the land and may meet with public resistance. Implementation of this alternative may be considered a “change in use” of the land under Article 97 of the Massachusetts Constitution.

Cost. The total installed cost for this alternative is approximately \$5,700,000. Annual operations and maintenance costs would accrue at a rate of \$970,000 per year for an estimated 9 years. The present value for life cycle expenses is approximately \$12,000,000. Costs presented above do not include the costs previously incurred for design and construction of the EW-1 treatment system (\$670,000) or the CWSW well-head treatment system (\$470,000). The shallow well-point system and berm construction costs (\$2,650,000) are not included either. (Sunk costs are presented for informational purposes only and are not taken into consideration in the decision making process.) With the implementation of this alternative, the ecology along the Coonamessett River may become accustomed to higher flows. If this change results in a condition in which it is not possible to shut the system off when remedial goals are met, substantial additional costs will be incurred to maintain increased flow to the Coonamessett River. Treatment described under this alternative could allow the CWSW wellhead protection system to discontinue operations earlier than under other alternatives. This could result in a cost reduction.

### 5.2.5 Comparison of Alternatives

Alternative 1 (no remedial action with long-term monitoring) is not an acceptable alternative because it fails to meet either threshold criteria. Alternative 3 (continued treatment system operations), Alternative 6 (continued remedial operations with capture north of the western arm of Coonamessett Pond) and Alternative 7 (continued remedial operations with additional extraction and treatment in the Souza conservation area) comply with both threshold criteria. Table 5-7 compares the four alternatives according to the Remedial Alternative Evaluation System presented in Section 4.2.

**Table 5-7  
FS-28 Comparison of Alternatives**

Evaluation Criteria	Alternative 1: No Remedial Action with Long-term Monitoring	Alternative 3: Continued Treatment System Operations	Alternative 6: Continued Remedial Operations with Capture North of the Western Arm of Coonamessett Pond	Alternative 7: Continued Remedial Operations with Additional Extraction and Treatment in the Souza Conservation Area
Overall Protection of Human Health and the Environment	No	Yes	Yes	Yes
Compliance with ARARs	No	Yes	Yes	Yes
Long-Term Effectiveness and Permanence	1	5	5	5
Reduction of Toxicity, Mobility or Volume through Treatment	0	4	4	4
Short-Term Effectiveness	1	4	4	1
Implementability	5	4	1	2
Cost (in millions)	\$3.4	\$7.1	\$15	\$12

Threshold Criteria. Alternative 1 fails to protect human health and the environment by allowing unacceptable levels of EDB to enter the Coonamessett River. Alternatives 3, 6 and 7 are protective of human health by preventing human contact with contaminated groundwater. A potential risk also exists from wading in or eating

fish from the Coonamessett River. Alternatives 3, 6 and 7 provide plume capture that will minimize short-term risks, long-term risks, and environmental exposure to EDB. Alternatives 6 and 7 also include actions that will speed aquifer restoration.

Alternatives 3, 6 and 7 comply with ARARs. These three alternatives will reduce the levels of groundwater contaminants to below statutory limits over different time frames (Table 5-8). The restoration time frames for the FS-28 plume are estimates of time needed to reduce EDB concentrations below the MMCL and are based on advective flow modeling. Refer to Appendix E for additional information concerning the results of fate and transport modeling of EDB within the FS-28 plume.

**Table 5-8  
Comparison of Alternatives: Approximate Cleanup Times**

	Alternative 1: No Remedial Action with Long-term Monitoring	Alternative 3: Continue Treatment System Operations	Alternative 6: Continue Remedial Operations with Capture North of the Western Arm of Coonamessett Pond	Alternative 7: Continued Remedial Operations with Additional Extraction and Treatment in the Souza Conservation Area
EDB (groundwater)	0.02 µg/L MMCL will be met in 18 years	0.02 µg/L MMCL will be met in 18 years	0.02 µg/L MMCL will be met in 11 years	0.02 µg/L MMCL will be met in 9 years
EDB (surface water)*	0.025 µg/L will be met in 5 years	0.025 µg/L will be met in 1 year	0.025 µg/L will be met in 1 year	0.025 µg/L will be met in 1 year

\* 0.025 µg/L is the 10<sup>-6</sup> risk equivalent concentration for a maximally exposed lifetime. This includes exposure as a child and adult wader, fisher and worker.

Appendix A, Tables 1 through 3 provide a comparison of each alternative's ability to comply with chemical-, location- and action-specific ARARs, respectively.

Because Alternative 1 fails to comply with threshold criteria, it will not be considered further.

Primary Balancing Criteria. Alternatives 3, 6 and 7 provide long-term effectiveness and are reliable. All of these alternatives will remove approximately the same mass

of contamination from the aquifer. Alternatives 3, 6 and 7 reduce contaminant mobility, toxicity and volume through treatment and satisfy the regulatory preference for treatment. All three of these alternatives allow a small amount of contamination that is currently downgradient of the well-point extraction system to remain uncaptured.

Unlike Alternative 3, Alternatives 6 and 7 will reduce the time until the aquifer is restored. This reduction could be as great as 50 percent (under Alternative 7). There is uncertainty involved in the time estimates provided. The following assumptions are incorporated into restoration time estimates:

- A single flush of clean water will be sufficient to remove EDB from the aquifer at the trailing edge of the plume.
- Hydrolysis will have some effect on EDB.
- A significant quantity of EDB is not present under the body of Coonamessett Pond (as opposed to the western arm).

In addition, no attempt has been made to adjust restoration times to account for the delay between data acquisition and treatment system start-up.

If EDB is not purged from the aquifer with a single flush of water or if hydrolysis is negligible, Alternatives 3, 6, and 7 will take longer to restore the aquifer. The time required for Alternative 3 to achieve aquifer restoration will increase disproportionately, and the time difference between Alternative 3 and Alternatives 6 and 7 will increase. If these two assumptions are not valid, the life cycle cost of all three alternatives will increase. These factors would increase the desirability of the additional actions presented in Alternatives 6 and 7. By speeding aquifer restoration and providing additional protection for the CWSW, Alternatives 6 and 7 minimize the potential risks.

If a significant amount of EDB is present under Coonamessett Pond, the additional treatment systems proposed under Alternatives 6 and 7 would not be able to act as



containment systems. This would significantly increase the time required for either of these two alternatives to achieve aquifer restoration and decrease the desirability of these alternatives.

Time estimates for all of the alternatives begin at the completion of remedial investigation data acquisition and assume immediate system start-up. The treatment aspects of Alternative 3 are currently in place. The northern treatment systems proposed under Alternatives 6 and 7 cannot be constructed until after additional data gathering and design work. This delay in system start-up (versus modeled system performance) decreases the time that the northern system would operate, increases the time the southern system would operate, and increases the time until aquifer restoration would be achieved under Alternatives 6 and 7.

Alternatives 6 and 7 would provide little additional effectiveness (risk reduction). This conclusion is based on four factors that are discussed in more detail below:

- because of converging flow, the existing treatment system effectively captures the plume;
- the low levels of contaminants that would be captured by additional treatment are being flushed from the aquifer by natural processes;
- residences located above the plume are connected to municipal water supplies and are unlikely to be exposed to measurable levels of contaminants under Alternative 3; and
- the CWSW has an existing carbon adsorption filter system and is unlikely to encounter contaminants in its influent.

The naturally-converging flow system containing the FS-28 plume is dominated by the Coonamessett River and affected to a lesser extent by Coonamessett Pond. Although other plumes within the SWOU are increasing in volume as they move downgradient, the converging flow field caused by the river is causing the FS-28 plume to narrow. The existing treatment system is well positioned to not only capture the highest concentrations of contaminants within the next several years (Figure 1-3), but also to take advantage of the converging flow field that will continue to draw plume contaminants toward the extraction well.

Natural processes are flushing EDB from the aquifer. The highest concentration of EDB ever measured in a sample collected north of Coonamessett Pond was 3.1 µg/L, measured in a January 1997 borewater sample from the boring at wells 69MW1402/1403/1405. The sample from monitoring well 69MW1403, screened at the elevation of the highest borewater result, had 1.1 µg/L of EDB. This monitoring well sample, collected in February 1998, over a year after well installation, represents the most recent and best estimate of maximum concentrations north of the pond. Similarly, the highest concentration of EDB in January 1997 borewater samples collected at wells 69MW1400A,B was 2.3 µg/L, and the result of the January 1998 sample from 69MW1400B, screened at the elevation of the highest borewater result, was 0.089 µg/L (one year after installation). Assuming an average linear velocity of 1.5 feet per day and assuming no retardation or dispersion, the groundwater that was sampled at and downgradient of 69MW1400A,B in 1997 would no longer be north of the pond. Continued flushing is also evident in recent samples taken north of Coonamessett Pond (Appendix D).

Table 5-9 presents the measured EDB concentrations in monitoring wells north of Coonamessett Pond where multiple samples had detectable concentrations of EDB when they were initially sampled. In each well, concentrations were less in the most recent sample, supporting the conceptual model that the aquifer is slowly restoring itself to background conditions as the plume flushes southward. Most of the EDB mass (more than 85 percent, Figure 5-1) is already downgradient of the additional treatment systems proposed under Alternatives 6 and 7. EDB will continue to migrate downgradient during system design and construction.

**Table 5-9**  
**EDB Concentrations in Resampled Wells North of Coonamessett Pond**

<b>Monitoring Well</b>	<b>Early EDB Result (µg/L)</b>	<b>Date</b>	<b>Recent Result (µg/L)</b>	<b>Date</b>
69MW1262	0.04	6/3/96	0.013	2/26/97
69MW1264	0.03	6/4/96	0.0097	2/25/98
69MW1268	0.02	6/3/96	0.011	2/26/97
69MW1271	0.03	5/31/96	0.023	3/10/98
69MW1272	0.09	5/22/96	0.013	2/18/98
69MW1275	0.05	5/21/96	0.046	1/29/97

Early EDB results from Ethylene Dibromide Phase II Investigation, reported in December 1996 Technical Memorandum prepared by ABB Environmental Services, Inc.

In April 1999, seven wells screened in the FS-28 plume north of the western arm of Coonamessett Pond and one well located south of the western arm of Coonamessett Pond were resampled for EDB. The results are presented in Appendix D. The 1999 data confirm that concentrations are being reduced over time.

The residences that overlie the FS-28 plume are connected to a municipal water supply. Most of these residences are located over the deep and dilute trailing edge of the plume. If future homes are constructed in the FS-28 plume area, water mains are available to connect those homes to the municipal water supply.

The highest concentrations of EDB present in the FS-28 plume are downgradient of the CWSW. To date, there has been no confirmed EDB contamination in CWSW influent. As time passes and the plume continues to migrate downgradient, the chances of contaminants entering the well will continue to decrease. A carbon adsorption filtration system was previously added to ensure that the water from the well is safe. Actions included in Alternative 6 and 7 would provide additional protection for the well but, because of the existing wellhead treatment system, this does not translate into reduced risk for consumers of water from the well. The distribution of plume contaminants also raises questions about the effectiveness of Alternatives 6 and 7 in providing additional protection for the CWSW.

If all contamination moves with the groundwater flow, Alternative 6 will remediate the aquifer approximately seven years sooner than Alternative 3. Under the same assumption, Alternative 7 would remediate the aquifer nine years sooner than Alternative 3. If multiple flushes of uncontaminated groundwater were required to remove EDB from the aquifer, remedial times for all alternatives would be longer and the difference between the times for Alternative 3 and Alternatives 6 and 7 would be greater. However, as discussed in the SWOU RI, degradation and dilution will continue to affect the FS-28 plume. The trailing edge of the plume is particularly subject to dilution because there are substantial volumes of uncontaminated groundwater within the body of the plume. In addition, degradation of EDB through hydrolysis will substantially reduce plume mass (AFCEE 1999c).

Alternative 3 will have minor environmental impacts. Alternative 6 would result in a significant volume of treated water flowing through Coonamessett Pond. Alternative 7 has significant environmental impacts to the Souza conservation area, Coonamessett Pond and the Coonamessett River. Alternative 7 would result in a system that assumes active control over area hydrology.

Construction aspects of Alternative 3 have already been implemented. Implementation of Alternatives 6 and 7 is likely to face significant administrative obstacles. If implementation of these alternatives is delayed, the benefits presented by these alternatives in terms of reduced time until aquifer restoration is achieved would be reduced.

Alternative 3 (\$7,100,000) is approximately twice as expensive as Alternative 1 (\$3,400,000). Alternatives 6 (\$15,000,000) and 7 (\$12,000,000) are approximately twice as expensive as Alternative 3. No capital costs are associated with Alternative 1. Capital costs associated with existing treatment facilities are sunk costs and are not taken in to consideration during the decision making process. Thus, no capital costs are associated with Alternative 3. More extensive construction and restoration costs cause Alternative 6 to have higher capital costs (\$8,800,000) than Alternative 7 (\$5,700,000).

The time required for remediation causes uncertainty in the operations and maintenance costs for all alternatives. Substantial sources of uncertainty in the cost estimates for Alternatives 6 and 7 include the number of extraction wells required, the type and number of discharge facilities required, the length of extraction and reinjection piping required, the required system flow rate, and potential budget impacts caused by delays in obtaining access.

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## 6.0 FS-29 PLUME

### 6.1 DEVELOPMENT AND SCREENING OF ALTERNATIVES

#### 6.1.1 Development of Alternatives

The FS-29 plume was discovered during the SWOU RI (AFCEE 1999c). Additional data to define the leading edge of the FS-29 plume have been collected since the publication of the SWOU RI and are included in Appendix D. Based on information in the SWOU *Remedial Technologies Identification and Screening Memorandum* (AFCEE 1998b) and input from regulatory agencies, the following remedial alternatives are being considered:

1. No remedial action with long-term monitoring.
2. Use institutional and engineering controls to prevent future residential exposure to FS-29 plume contaminants.
3. Construct a groundwater ETR system using granular-activated carbon treatment. The purpose of this alternative would be capture of the plume.
4. Construct a groundwater ETR system using granular-activated carbon treatment. The purpose of this alternative would be mass removal.
5. Use recirculating wells to remove plume contaminants.
6. Use mobile carbon treatment systems as defined in Section 3.2.4.5 to capture the central portion of the plume.
7. Construct and operate a new ETR system to capture the central portion of the plume.

Since the SWOU Feasibility Study was issued, AFCEE has proposed active treatment systems for the CS-21 plume (Figure 6-1). Analysis of the above alternatives assumes that these treatment systems are in place. According to advective flow modeling, the most upgradient section of the FS-29 plume will be captured by the proposed CS-21 treatment system.

## **6.1.2 Screening of Alternatives**

### **6.1.2.1 Alternative 1: No Remedial Action with Long-Term Monitoring**

This alternative includes no action to reduce risk from FS-29 plume contamination. It includes provisions for monitoring the plume. Because no known pathways currently exist for exposure, this alternative may be effective at protecting human health. Due to the degradation and dispersion of plume contaminants, this alternative may also be able to protect human health over the long-term. This alternative can be easily implemented at less cost than the other alternatives under consideration. Therefore, this alternative will receive detailed analysis and will serve as a baseline against which other alternatives are compared in accordance with § 300.430(e)(3) of the NCP.

### **6.1.2.2 Alternative 2: Institutional and Engineering Controls**

Human health could be protected through existing bylaws or by establishing covenants that prevent the drilling of private wells above areas currently contaminated or likely to be contaminated in the future. Similarly, the use of existing private wells could be limited through regulations or with voluntary agreements once the properties are connected to public drinking water supplies. Wellhead protection treatment systems could be used to protect potential public water supplies.

Some institutional controls are already in place to prevent human exposure to FS-29 plume contaminants. Any future drinking water supply well drilling in the Crane Wildlife Area requires approval by the Massachusetts Legislature. All public drinking water supplies within Massachusetts are protected by DEP regulations. The Falmouth Board of Health recently approved additional regulations in order to minimize and prevent the consumption or use of contaminated water from private wells.

In addition to institutional controls, a wellhead protection system could be used to ensure that if a public water supply well were to be installed at the proposed water supply well site, the public water supply would remain safe.



It is extremely unlikely that FS-29 plume contaminants will ever reach detectable levels in surface water bodies. Therefore, there is little or no risk to the environment. This alternative could be effective in protecting human health from contaminated groundwater. Previous attempts to permanently seal and abandon residential wells, after the houses were connected to public water supplies, encountered fierce resistance and the threat of litigation. Implementation of institutional controls presented under this alternative would rely on the Town of Falmouth. Public water supply service connections and institutional controls are expected to be effective in restricting exposure to contaminated groundwater. However, the risk of exposure cannot be completely eliminated since some existing wells have not been sealed or abandoned. Therefore, there may be difficulty in implementing this alternative. Costs for this alternative would be low compared to active treatment alternatives. This alternative will be carried forward for detailed analysis.

#### **6.1.2.3 Alternative 3: Extraction, Treatment and Reinjection for Plume Capture**

Alternative 3 consists of an ETR system with a series of extraction wells, treatment using granular-activated carbon and an infiltration gallery. The objective of this alternative is plume capture and containment. Pretreatment using greensand filtration or settling will be considered, if necessary. Reinjection wells will be evaluated if excessive mounding is a concern. This alternative includes performance monitoring of the treatment system and monitoring of the plume itself. Ecological monitoring and institutional controls are also included. Institutional controls are included in this alternative and will remain in place until the contaminant concentrations in the aquifer are below drinking water standards. Both carbon tetrachloride (CCl<sub>4</sub>) and EDB are highly soluble in water, and an ETR system could effectively remove plume contaminants, thereby reducing the potential for long-term risk. Because of the discontinuous distribution and highly dilute nature of the plume, the efficiency of such a system may be low. Administratively, portions of this alternative may be difficult to implement, because the plume underlies Crane Wildlife Area and a residential community. Technically, there are few obstacles to implementing this

alternative; however, high iron levels in plume groundwater are a concern. The cost of this alternative is high compared to other alternatives. This alternative will be considered during detailed analysis.

#### **6.1.2.4 Alternative 4: Extraction, Treatment and Reinjection for Mass Removal**

This alternative is a scaled down and less expensive version of Alternative 3. Instead of plume containment, the goal of this alternative would be to reduce plume mass. This alternative was considered to determine if there is a possibility that considerably lower pumping rates could be used that would still capture a large proportion of the contaminant mass present. Like Alternative 3, Alternative 4 consists of an ETR system with one or more extraction wells, treatment using granular-activated carbon, and an infiltration gallery. Pretreatment using greensand filtration, settlers, or clarifiers would be considered, if necessary. If mounding is a concern, the use of reinjection wells would be considered. This alternative includes performance monitoring of the treatment system, monitoring of the plume itself, ecological monitoring, and institutional controls. Institutional controls are included in this alternative and will remain in place until the contaminant concentrations in the aquifer are below drinking water standards.

According to the available data, the FS-29 plume lacks any distinct volumes of high concentrations of contaminants. It consists of two lobes of relatively uniform low levels of contaminants, separated by a layer of clean water. The physical distribution of contamination (Figure 1-4) provides little opportunity for a low-flow pumping scenario capable of capturing a substantial portion of plume contaminants using a limited number of extraction wells.

This alternative might be considered a viable treatment alternative if a substantial percentage of plume mass could be contained at a considerably lower cost per unit mass than an ETR system designed to capture and contain the plume. For instance, if 80 percent of the plume mass could be captured at 50 percent of the cost, this type of an alternative may warrant further consideration. Because of the dispersed and

discontinuous nature of the plume, it is unlikely that a pumping scenario could be developed that would be able to capture groundwater with significantly higher concentrations of contaminants than a full containment system without requiring significantly more extraction wells.

Difficulties that will be encountered in implementing this alternative are similar to those entailed with Alternative 3. Of potential concern are access issues involved with construction in the Crane Wildlife Management Area and the residential area south of Route 151. Because lower flows of groundwater are to be treated, operations and maintenance expenses for this alternative would be lower than for Alternative 3. However, assuming that the Alternative 3 treatment system can be designed with flow that can be treated with a single pair of carbon adsorbers (600 gpm), capital costs may not be significantly different.

Although this alternative is less costly than Alternative 3, the amount of risk reduction it provides appears to decrease in direct proportion to cost savings. For the remediation of this particular plume, if a permanent ETR system is going to be designed, constructed and operated, it should aim at total plume capture and not mass reduction. This alternative will not receive detailed analysis.

#### **6.1.2.5 Alternative 5: Recirculating Wells**

Recirculating wells could potentially be used to remediate the FS-29 plume. The discussion of this alternative focuses on three distinct aspects of implementing this technology for this specific plume: the use of recirculating wells to treat semi-volatile contaminants, the lithology and physical distribution of plume contaminants, and the advantages and disadvantages of recirculating wells versus ETR systems.

As discussed in Section 1.1, this FS-29 plume consists of relatively small masses of EDB and CCl<sub>4</sub> diluted in a large volume of groundwater. Remedial actions undertaken for the FS-29 plume must be able to remove EDB, a semi-volatile compound. Based on its Henry's Law Constant (Table 3-1), EDB will not readily

strip in a recirculating well air stripper. However, recirculating wells can be modified to treat contaminants with liquid-phase carbon, which would either be located aboveground or immediately below the ground surface. This arrangement creates what is, for all practical purposes, a small ETR system with extraction and reinjection occurring in the same well.

Because of the paired extraction and reinjection arrangement, the success of recirculating well technology in treating a given groundwater plume is necessarily highly dependent on lithology. The FS-29 plume is composed of two vertical lobes (Figure 1-4) separated by a layer of uncontaminated water. The trailing edge of the upper lobe is not a suitable location for a recirculating well because it is bisected horizontally by a silt layer; the silt will hamper complete extraction at this location. Because the location is upgradient of the bulk of the contamination, it is not a desirable extraction location. The body and leading edge of both plume lobes are located in sand that is interspersed with silty sand stringers. The lower lobe appears to be directly above and interspersed with a basal layer of silty sand. For this part of the plume, a recirculating well with two recirculating cells could be designed.

When used in the proper applications, recirculating wells offer a number of advantages in comparison to ETR systems: they require less space, they can be located underground, they can be used to minimize drawdown, and recirculation can be used to desorb contaminants from the aquifer matrix and remove contaminants by vertical advection from horizontal layers of lower conductivity zones. The plume is located under Crane Wildlife Area, a golf course, and residential neighborhoods. The use of small, subterranean treatment units may decrease administrative difficulties with remedial construction in this area. However, the minimization of treatment system drawdown is of marginal benefit in this area because of the lack of surface water bodies, other than lined, man-made golf course ponds. In this case, recirculation is not advantageous because the vast majority of plume contaminants are in the aqueous phase. Sorbed contaminants and high concentrations of contaminants in low-conductivity zones are not present. Given the discontinuous nature of plume

contaminants (Figure 1-4), any system extracting water from the body of the plume will necessarily also remove a high proportion of uncontaminated water. Recirculation will decrease treatment efficiency by necessitating the re-treatment of discharged water.

In comparison to an ETR system, recirculating wells will be more expensive. The recirculating well system described above is, in essence, a self-contained ETR system because groundwater treatment would have to occur at or just below the ground surface. This configuration lacks the benefits of scale provided by a more conventional ETR system. Recirculation would also necessitate that the recirculating well system be capable of treating larger volumes of groundwater than a comparable ETR system. (Institutional controls are included in this alternative and would remain in place until the contaminant concentrations in the aquifer are below drinking water standards.) According to the National Contingency Plan, “alternatives providing effectiveness and implementability similar to that of another alternative by employing a similar method of treatment or engineering control, but at greater cost, may be eliminated” (40 CFR 300.430(e)(7)(iii)). For this reason, recirculating wells will not receive detailed analysis as a remedial alternative for the FS-29 plume.

#### **6.1.2.6 Alternatives to Capture the Central Portion of the FS-29 Plume**

For the purpose of discussion, the FS-29 plume has been divided into three sections (Figure 6-2). Alternatives to capture the central portion of the FS-29 plume are also being considered. As with other FS-29 plume alternatives, analysis of these alternatives assumes that the upgradient portion of the plume will be captured by the proposed CS-21 treatment system. Contamination in the distal portion of the plume would go uncaptured under these alternatives.

Previous developers (Longshank Nominee Trust) of the land, currently managed by the Ballymeade Development Corporation, installed a pilot water supply well. The well site is to the southeast of the FS-29 plume. The Ballymeade Well had a pumping test performed in the 1980s and a Zone II was generated.

Falmouth has previously listed the pilot water supply well site as a possible location for a drinking water supply well. Even though there is no current agreement to develop the site between the town and Ballymeade, the well has been and is being considered as a possible future supply for the Town of Falmouth. The well site has been identified as a potential future water supply site in the Earth Tech report *Regional Water Supply Study and Development of MMR and Upper Cape Cod, Massachusetts*, dated November 1998. Figure 6-3 shows the Zone II for this pilot water supply well. The influence of treatment systems proposed for other SWOU plumes will significantly alter the actual zone of contribution to the well. The well is not permitted. (A different potential well site, the proposed well site at Crooked Pond is cross-gradient to the FS-29 plume and will not be impacted by the plume.)

This well site is located approximately 1000 feet southeast of the FS-29 plume. Monitoring well 69MW1540 was drilled adjacent to the supply well, which is screened near the top of the aquifer. Contaminants of concern were not detected in borewater samples or subsequent samples collected from monitoring well 69MW1540. Based on the available information, it does not appear that extraction of groundwater at this site would be impacted by the FS-29 plume. The following two alternatives are being considered to provide additional protection for this potential well site by remediating the central portion of the plume:

- Use mobile carbon treatment systems as defined in Section 3.2.4.5 to capture the central portion of the plume.
- Construct and operate a new ETR system to capture the central portion of the plume.

The central portion of the FS-29 plume would be captured by either of these two alternatives. The distal portion of the FS-29 plume, downgradient of the central portion, would not be subject to capture by these two alternatives.

The proposed CS-21 treatment system would pull contaminants further west, away from the proposed well site. Advective flow modeling indicates that with the proposed CS-21 treatment system operating, FS-29 plume contaminants will travel

well to the west of the proposed well site. Significant additional protection could be afforded to the proposed well site through careful placement of infiltration galleries from the proposed CS-21 and CS-20 treatment systems.<sup>9</sup>

#### **6.1.2.7 Alternative 6: Mobile Carbon Treatment to Capture the Central Portion of the Plume**

Like Alternative 4, mobile carbon treatment offers an opportunity to treat plume contaminants short of full plume capture. This alternative would focus treatment on the central portion of the FS-29 plume in order to provide additional protection to the proposed well site south of the plume. This alternative would include mobile carbon treatment, performance monitoring, plume monitoring, and institutional controls, which would remain in place until contaminant concentrations in the aquifer are below drinking water standards.

At each mobile carbon treatment system, extraction would take place at a rate of approximately 100 gpm through a pair of extraction wells (50 gpm per well). One well would be screened in the upper lobe of the plume and the other would be screened in the lower lobe. Power would be supplied by a trailer-mounted diesel generator.

Extracted water would be pumped through a pair of dual bag filters. These filters would remove suspended solids, including any metals that had come out of solution. CCl<sub>4</sub> and EDB would be removed by a pair of carbon adsorbers, each 5 feet in diameter and containing 3,000 pounds of activated carbon. The bag filters and carbon vessels would be housed in a large container (commonly referred to as a sea container or conex). Once the system was disconnected and drained, it could be moved.

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<sup>9</sup> A different public water supply well has been proposed for a site near Crooked Pond. This is cross-gradient to the FS-29 plume and will not be impacted by that plume.

Because the treatment system is mobile and can be brought to the extraction well, the length of dual contained piping required is minimized. Because of the low flows involved and the depth of the plume, an infiltration gallery could be located at each pair of extraction wells to discharge treated water above the plume. Multiple extraction locations could be used and the treatment system could be rotated from one extraction point to the next. Other potential advantages of this type of alternative include potentially higher influent concentrations compared to a standard ETR system and more flexibility than a permanent system in locating the system in some areas.

For the FS-29 plume, mobile systems would likely be located in the Crane Wildlife Management Area or a residential area south of Route 151. The systems may be vulnerable to vandalism, particularly if a generator is being used. A mobile system may be more acceptable to area residents than a permanent system, particularly if a date for system removal is agreed to in advance. Noise from a generator may be viewed as esthetically undesirable in a residential area and disruptive to wildlife in a wildlife management area. A mobile system may be vulnerable to fouling due to high iron levels in the FS-29 plume. Iron levels may be beyond the capacity of the bag filters and additional pretreatment may be required.

Costs for the treatment process units in an enclosed, winterized container are relatively inexpensive when compared to a permanent ETR system. Even when combined with an electric generator, these capital costs will be less than \$100,000. In addition, the cost for piping is minimized. However, the costs associated with each extraction location are relatively high. Each extraction location requires two 8-inch extraction wells (one for the upper lobe and one for the lower lobe), an infiltration gallery, and dedicated pumps. On a per gallon basis, operational costs for mobile carbon treatment systems are high. Each system would require daily attention to refuel the generator and inspect the bag filters. Sampling requirements and costs would be significantly higher for multiple systems than for a single, larger ETR system.



In addition to susceptibility to vandalism and fouling, mobile carbon treatment systems have other significant disadvantages that limit their ability to accomplish the remedial action objectives for this plume. As discussed in Section 3.2.4.5, mobile carbon systems have limited flow capacity and are not well suited to extended operations. Mobile treatment units are poorly suited to the mission of containing a large groundwater plume. These systems, as currently envisioned, have neither the flow capacity nor the design life expectancy to contain the hundreds of millions of gallons that make up the central portion of the FS-29 plume. For these reasons, this alternative will not be considered during detailed analysis.

#### **6.1.2.8 Alternative 7: Extraction, Treatment and ReInjection to Capture the Central Portion of the FS-29 Plume**

This alternative would include a modular ETR system to capture and treat the central portion of the FS-29 plume. Also included are plume, operational, and ecological monitoring. The ETR system would include extraction wells, granular-activated carbon, and reinjection wells. Institutional controls are included in this alternative and would remain in place until the contaminant concentrations in the aquifer are below drinking water standards. It is likely that greensand filtration and the accompanying backwash and sedimentation vessels and pumps would be required. The goal of this system would be to capture the central portion of the plume.

This alternative could effectively capture the central portion of the plume. High iron levels may cause operational difficulties. Acquiring access for the required construction may be difficult. Costs for this alternative are likely to be similar to

Alternative 3, which has much in common with this alternative. This alternative will be considered during detailed analysis.

## **6.2 DETAILED DESCRIPTION AND EVALUATION OF ALTERNATIVES**

The following remedial alternatives will receive detailed consideration for the FS-29 plume: Alternative 1—No Remedial Action with Long-Term Monitoring;

Alternative 2— Institutional and Engineering Controls; Alternative 3—Extraction, Treatment and Reinjection for Plume Capture; and Alternative 7—Extraction, Treatment and Reinjection to Capture the Central Portion of the FS-29 Plume.

#### **6.2.1 Alternative 1: No Remedial Action with Long-Term Monitoring**

The no-remedial action with long-term monitoring alternative consists of sampling and analysis to monitor the FS-29 plume. This alternative does not include any active measures to remove, destroy or immobilize contamination. Under this alternative, no steps would be taken to prevent human exposure to contaminated groundwater. In accordance with § 300.430(e)(3) of the NCP, this alternative serves as a baseline against which other alternatives are compared. The monitoring program is intended to track changes in the location and concentration of plume contaminants over time, but it is not intended to be a demonstration of natural attenuation. This alternative does include incidental capture of FS-29 plume contaminants by the proposed treatment system for the CS-21 plume.

Although no active remedial action is included in this alternative, natural processes, primarily dispersion and abiotic degradation, will continue to influence the FS-29 plume (AFCEE 1999c).

The monitoring program would consist of sampling and analysis at monitoring wells within the body of the plume, downgradient of the plume, and to either side of the expected trajectory of the plume. This monitoring program would have to specifically address protection of human health. Specifically, the information gathered under this alternative must be sufficient to assess whether human health is being protected. Due to plume migration, it is estimated that two additional downgradient monitoring wells will need to be drilled every three years. In addition, there are two irrigation wells that will require semiannual sampling. All samples would be analyzed for EDB and VOCs in accordance with the *Quality Program Plan* (AFCEE 1998g). Sampling and analysis would be performed semiannually for the first two years and annually thereafter. (Monitoring details presented were used for

cost estimating. Actual monitoring requirements would be developed during remedial design.) For as long as plume contaminants remain above cleanup standards, a thorough site review would be conducted every five years.

Table 6-1 presents a summary of the evaluation of Alternative 1 according to CERCLA evaluation criteria and the Remedial Alternative Evaluation System presented in Section 4.2. A discussion of the evaluation follows.

**Table 6-1  
Evaluation of Alternative 1: FS-29 Plume**

<b>Evaluation Criteria</b>	<b>Value</b>
Overall Protection of Human Health and the Environment	No
Compliance with ARARs	Yes
Long-Term Effectiveness and Permanence	3
Reduction in Toxicity, Mobility and Volume Through Treatment	1
Short-Term Effectiveness	5
Implementability	4
Cost (present value, millions of dollars)	\$0.97

Overall Protection of Human Health and the Environment. Alternative 1 does not adequately protect human health and the environment. Concentrations of CCl<sub>4</sub> and EDB in the groundwater currently exceed MCLs and MMCLs. There are no known completed pathways to expose human beings or the environment to this contamination; however, this alternative lacks the institutional controls needed to restrict new well installation over the plume. If new wells were installed over the plume, under this alternative, no sampling of these wells would take place.

It is also possible that private wells exist and are being used in the area of the plume, despite numerous efforts that have been made to inform residents south of MMR of groundwater quality problems. However, given the availability of publicly supplied drinking water, residents (whose homes have been connected to public water supplies) with private wells are unlikely to use their well water for drinking or bathing.

Based on available information, it does not appear that extraction of groundwater at the proposed municipal well site south of the FS-29 plume would be impacted by FS-29 plume contaminants. However, if this site is developed for a municipal water supply in the future, permit approval should take into consideration the potential impacts of contamination in the upgradient zone of contribution, which could include the FS-29 plume.

Compliance with ARARs. Currently, the concentrations of contaminants within the FS-29 plume exceed regulatory standards. Based on the assumptions described above, this alternative will eliminate these concentrations above the drinking water standard in 13 to 17 years from the date of data acquisition. This alternative can be implemented in a manner that complies with location- and action-specific ARARs (Appendix A, Tables 4 through 6).

Long-Term Effectiveness and Permanence. Given the published data for the hydrolysis kinetics of EDB and the long travel times involved before the water that currently occupies the FS-29 plume will discharge to surface water bodies, this alternative is expected to effectively disperse and degrade EDB before discharge can occur. Dispersion will reduce the maximum concentrations of the EDB and  $\text{CCl}_4$  present, but may also increase the volume of groundwater impacted by the plume. As discussed in Section 3.1.4, EDB may undergo abiotic degradation by hydrolysis that results in a half-life of 5.4 to 7.2 years under local groundwater conditions. (The reader is cautioned to treat all half-life data as approximate.) Destruction of EDB at this rate would have a significant impact on the mass of EDB present within the plume. In addition, because a large portion of the plume consists of water with EDB concentrations only slightly above the MMCL of  $0.02 \mu\text{g/L}$ , small decreases in the mass of EDB present would result in large decreases in the volume of the plume (as defined by the MMCL).

Of particular interest is a boring water sample taken at 69MW1536 (at approximately -65 to -69 feet msl). This sample contained  $0.108 \mu\text{g/L}$ , the highest concentration of

EDB detected within the FS-29 plume. Assuming that this is the highest concentration of EDB actually present within the plume, a degradation half-life of between 5.4 and 7.2 years, and no dispersion, EDB concentrations would be below the MMCLs in 13 to 17 years (see AFCEE 1999c, Section 5.1.5.1 for a discussion of first-order degradation). (To compare these times to those presented for active treatment alternatives, it is necessary to subtract three years in order to account for the delay between data acquisition and system start-up.<sup>10</sup>)

Hydrolysis and biodegradation are probably not significant degradation processes for CCl<sub>4</sub>. Under this alternative, the mass of CCl<sub>4</sub> will likely be relatively constant. CCl<sub>4</sub> exceeded its MCL (5.0 µg/L) at only four wells: 69MW1522A (5.0 µg/L); 69MW1536A (5.3 µg/L); 69MW1542 (5.9 µg/L); and 69MW1543 (9.5 µg/L). At MMR, a plume is generally defined as multiple detections in excess of the MCL or MMCL at multiple wells. With only four detections, three of which are not significantly in excess of the MCL, dispersion could decrease CCl<sub>4</sub> to concentrations below the standard set forth in the plume definition in a relatively short time. The effects of dispersion are irreversible.

The upgradient portion of the FS-29 plume intersects with the CS-21 plume. According to advective flow modeling, incidental capture by the proposed CS-21 plume treatment system will result in approximately 23 percent of the EDB in the FS-29 plume being removed (Figure 6-4). Approximately 77 percent of the EDB in the FS-29 plume would remain uncaptured. Natural processes are expected to reduce contaminant concentrations within the current plume to background levels; however this will require more time than under active treatment alternatives.

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<sup>10</sup> The modeling used to determine remedial times for no remedial action alternatives is based on the data presented in the SWOU RI. Times for these alternatives essentially began as soon as data collection for the RI was completed in 1998. Times for active treatment alternatives do not begin until treatment system start-up. The three years mentioned are necessary to account for this lag.

trichloroethene (TCE) is generally considered to be strong evidence that anaerobic degradation of TCE occurred at some point or is still occurring. Similarly, the presence of vinyl bromide could be considered as evidence of the hydrolysis of EDB. However, given the EDB concentrations of concern within the FS-29 plume, the concentrations of vinyl bromide that could be reasonably expected are well below the detection limit. A method detection limit (MDL) study was conducted in December, 1996 by Quanterra Environmental Services in Tampa, Florida for vinyl bromide by EPA method OLC02.1. The MDL study showed that vinyl bromide could be detected by this method at 0.1 µg/L if the gas chromatograph/mass spectrophotometer (GC/MS) instrument was calibrated for the compound.

Another possible method for demonstrating the degradation of a compound is to show decreasing concentrations over time. Decreasing concentrations may be a result of either degradation or dispersion or both. Monitoring under this alternative will focus on tracking plume concentrations and movement, not on demonstrating hydrolysis. The feasibility study presented a hydrolysis half-life for EDB of 5.4 to 7.2 years. Assuming that EDB actually degrades with a half-life of 7.2 years, if a round of sampling were to be conducted three years after the initial data were collected, the average EDB concentration within the plume would have decreased by 25 percent. However, variability in the individual samples as groundwater moves could also cause the observed average EDB concentration to increase. Given the dynamics of the plume and the statistical uncertainty of the data, even if hydrolysis is acting at the rates discussed, it will be very difficult to demonstrate.

It must be emphasized that although the time estimate for this alternative assumes that hydrolysis is occurring, the time estimate completely ignores dispersion, which fate and transport modeling indicate will strongly influence the plume (Appendix E).

Minor administrative difficulties are associated with sampling existing monitoring wells. Sampling within the Crane Wildlife Management Area must take into account the limitations imposed by hunting season. There are also access considerations

involved with drilling additional monitoring wells, which will be required to monitor the plume in future years.

Cost. Annual costs to implement this alternative are approximately \$100,000. The present value of life cycle costs is approximately \$970,000, assuming that monitoring will be conducted for 17 years. Uncertainty exists in the time required to achieve cleanup standards, and longer remedial times would result in higher costs.

### **6.2.2 Alternative 2: Institutional and Engineering Controls**

This alternative includes no actions to speed the remediation of the FS-29 plume. The goal of this alternative is to protect human health by eliminating potential exposure pathways. In addition to existing institutional controls (Section 6.1.2.2), this alternative includes long-term monitoring of the plume, additional institutional controls, and engineering controls. Plume monitoring activities would be the same as those presented in Alternative 1. This alternative also includes incidental capture of FS-29 plume contaminants by the proposed treatment system for the CS-21 plume. As discussed under Alternative 1, natural processes will continue to impact the FS-29 plume.

The Falmouth Board of Health approved a series of water well regulations at its September 13, 1999 meeting. These regulations require a permit from the Board of Health for the installation and use of all wells, including drinking water wells, irrigation wells, and monitoring wells within the town of Falmouth. (The FS-29 plume, as currently defined, falls entirely within the town of Falmouth.) Along with other requirements, this regulation states that “A Drinking Water Well must [be] tested for...volatile organic compounds and found to be within potable water limits as defined in 310 CMR 22.000 Drinking Water Regulations and must not exceed the Commonwealth of Massachusetts’ Maximum Contaminant Levels.” AFCEE will continue to work with the Board of Health to make sure that the Board of Health has the information needed to make informed decisions regarding well permitting.

Institutional controls presented in this alternative should remain in place until contaminant of concern concentrations are below cleanup standards. Cleanup standards are defined as the most stringent of MCLs, MMCLs, or risk-based standards if no MCLs or MMCLs are available.

This alternative includes measures to provide wellhead protection for the well site south of the FS-29 plume. To date no decision has been reached to develop this well and the well is not permitted. This well site is located approximately 1000 feet southeast of the FS-29 plume. Based on available information, it does not appear that groundwater extracted at this site would be impacted by the FS-29 plume. However, if this site were to be developed as a municipal water supply in the future, this alternative would include a wellhead protection system to treat extracted water. The system would be similar to the wellhead protection system installed at the CWSW site (two 20,000-pound carbon vessels, well water to backwash the carbon, and a temporary tank to hold spent backwash water). The wellhead protection system would only be installed if the decision to install the well were made.

Table 6-2 presents a summary of the evaluation of Alternative 2 according to the Remedial Alternative Evaluation System presented in Section 4.2. A discussion of the evaluation follows.

**Table 6-2**  
**Evaluation of Alternative 2: FS-29 Plume**

<b>Evaluation Criteria</b>	<b>Value</b>
Overall Protection of Human Health and the Environment	Yes
Compliance with ARARs	Yes
Long-Term Effectiveness and Permanence	3
Reduction in Toxicity, Mobility and Volume Through Treatment	2
Short-Term Effectiveness	5
Implementability	3
Cost (present value, millions of dollars)	\$3.1

Overall Protection of Human Health and the Environment. This alternative adequately protects human health and the environment. There are no known



completed pathways to expose human beings or the environment to contaminants of concern from this plume. Private wells may exist in the area of the plume and could be used despite numerous efforts that have been made to inform residents south of MMR of groundwater quality problems. However, given the availability of publicly supplied drinking water, residents with private wells are unlikely to use their well water for drinking water or bathing.

Compliance with ARARs. Currently, the concentrations of contaminants within the FS-29 plume exceed regulatory standards. Based on the assumptions described above, this alternative will eliminate these concentrations above the drinking water standard in 13 to 17 years from the date of data acquisition. This alternative can be implemented in a manner that complies with location- and action-specific ARARs (Appendix A, Tables 4 through 6).

Long-Term Effectiveness and Permanence. Given the published data for the hydrolysis kinetics of EDB and the long travel times involved before the impacted water will discharge to surface water bodies, this alternative is expected to effectively disperse and degrade EDB. EDB is expected to undergo abiotic degradation by hydrolysis that results in a half-life of 5.4 to 7.2 years under local groundwater conditions. (The reader is cautioned to treat all half-life data as approximate.) As discussed in Section 6.2.1, EDB concentrations would be below the MMCLs in 13 to 17 years from the date of data acquisition. (To compare these times to those presented for active treatment alternatives, it is necessary to subtract approximately three years in order to account for the delay between data acquisition and system start-up.) The mass of  $\text{CCl}_4$  will likely be relatively constant, but dispersion could decrease  $\text{CCl}_4$  to concentrations below the standard set forth in the plume definition in a relatively short time. The effects of dispersion are irreversible.

The upgradient portion of the FS-29 plume intersects with the CS-21 plume and will be subject to incidental capture by the proposed CS-21 plume treatment system. Modeling indicates that approximately 23 percent of the EDB in the FS-29 plume will be captured. This alternative does not include additional capture or active treatment

of contamination, except for wellhead treatment. Approximately 77 percent of the EDB in the FS-29 plume would remain uncaptured. Natural processes are expected to reduce contaminant concentrations within the current plume to background levels; however this will require more time than active treatment alternatives.

No impacts to existing private or municipal wells are anticipated under this alternative since residents downgradient of the FS-29 plume are connected to municipal water supplies. A wellhead protection system would protect the only known potential water supply well site (the Ballymeade well near 69MW1540). No unacceptable human health or environmental impacts from uncaptured contaminants are anticipated. Public perception of plume risks may cause negative socioeconomic impacts.

Reduction of Toxicity, Mobility, or Volume Through Treatment. Under this alternative, a portion of the FS-29 plume will be incidentally captured by the proposed CS-21 treatment system. If needed, a wellhead protection system would be constructed for the proposed Ballymeade water supply well. This system may also incidentally capture some FS-29 plume contamination.

Short-Term Effectiveness. Implementation of this alternative would not involve extensive intrusive activities. It is not anticipated that implementation of this alternative would have negative impacts on the community, worker safety, or environmental quality. It is believed that this alternative would achieve drinking water standards in the aquifer within 13 to 17 years from the date of data acquisition.

Implementability. There are no significant technical difficulties associated with the implementation of this alternative. See the implementability section under Alternative 1 (Section 6.2.1) for a discussion about difficulties expected to be encountered in demonstrating hydrolysis under local groundwater conditions. Minor administrative difficulties are associated with sampling of existing monitoring wells, because sampling within the Crane Wildlife Management Area must take into account the limitations imposed by hunting season. There are also access

considerations involved with drilling additional monitoring wells which will be required to monitor the plume in future years.

Cost. Life cycle costs for this alternative are approximately \$3,100,000, including annual expenses of \$270,000 for 17 years. Uncertainty exists in the time required to achieve cleanup standards, and longer remedial times would result in higher costs.

### **6.2.3 Alternative 3: Extraction, Treatment and Reinjection for Plume Capture**

This alternative includes the construction of an ETR system capable of treating 600 gpm to hydraulically capture and treat plume contaminants. Also included in this alternative are long-term monitoring of the plume, performance monitoring and evaluation of the treatment system, and ecological sampling to monitor the impacts of the system on the environment. The institutional controls included in Alternative 2 would be included in this alternative.

Modeling of this alternative assumed the presence of an active treatment system for the CS-21 plume. It also was assumed that treatment requiring more than 600 gpm would not be acceptable to the stakeholders involved, in light of the minimal amount of contamination present.

Active treatment of the CS-21 plume has a substantial impact on the flow paths of water in the upper portion of the FS-29 plume. In scenarios where capture of the CS-21 plume was evaluated, a significant portion of the mass in the upgradient portion of the FS-29 plume was captured by CS-21 plume extraction wells (Figure 6-2).

A project execution plan and a design plan would be required to implement this alternative. As part of the detailed design of this ETR system, additional data would be needed. Numerous additional borings would need to be installed. The average depth of each boring would be approximately 300 feet. Two wells would be installed in each boring, the wells would be developed, and the developed wells sampled. As

far as practical, these wells would also be used for performance monitoring evaluation of the ETR system. All samples would be analyzed for VOCs and EDB. (Monitoring details presented were used for cost estimating. Actual monitoring requirements would be developed during remedial design.)

The most effective scenario modeled for the capture and remediation of the FS-29 plume required two extraction wells and an infiltration gallery. One extraction well was located at the leading edge of the plume. The second extraction well was located along the axis of the FS-29 plume, directly south of the leading edge of the CS-21 plume. An aquifer pumping test would be required at one of these locations to aid in system design. Modeled infiltration took place outside of the plume footprint, to the southwest of the two extraction wells. The location of both extraction wells and the infiltration gallery would fall within the Ballymeade residential housing development.

The nearest potentially acceptable location for a treatment plant would be east of Route 28 and west of the residential area. This would require approximately 4000 feet of extraction well pipeline and approximately 4200 feet of reinjection well piping. An estimated 500-foot long access road would be required.

The expected influent for this system (Table 6-3) was based on samples taken in the vicinity of the proposed extraction well locations. The high iron and manganese present in the vicinity of these locations suggests that greensand filtration may be necessary for pretreatment upstream of the carbon filters.

**Table 6-3**  
**Alternative 3: Expected Treatment System Influent**

<b>Constituent</b>	<b>Maximum Influent Concentration (µg/L)</b>	<b>Long-term Influent Concentration (µg/L)</b>
CCl <sub>4</sub>	3	0.26
EDB	0.031	0.003
TCE	2	0.18
Total Iron	941	470
Total Manganese	415	200

Long-term influent concentration is the weighted average over the first five years of operation, based on data presented in Appendix B. Weighted average EDB influent concentration over the anticipated life of the remedial action would be approximately 0.007 µg/L.

If this alternative is implemented, it would also be necessary to prepare a sampling and analysis plan and a performance monitoring evaluation plan. Because of the numerous ponds downgradient of the plume, an extensive ecological sampling program would be required.

The long-term monitoring program would consist of sampling and analysis at monitoring wells within the body of the plume, downgradient of the plume, and to either side of the expected trajectory of the plume. Operational monitoring will require monthly samples of system influent, effluent, and flow between carbon vessels. Additionally, samples would be collected from each extraction well twice each year. All samples would be analyzed for EDB and VOCs in accordance with the *Quality Program Plan* (AFCEE 1998g). Sampling and analysis of monitoring wells would be performed semiannually for the first two years and annually thereafter until samples have no detectable levels of plume contaminants for two consecutive sampling events. Institutional controls are included in this alternative and will be maintained until cleanup standards are met. As long as plume contaminants remain above cleanup levels, a thorough site review would be conducted every five years.

Table 6-4 presents a summary of the evaluation for Alternative 3 according to CERCLA evaluation criteria. A discussion of the evaluation follows.

**Table 6-4**  
**Evaluation of Alternative 3: FS-29 Plume**

<b>Evaluation Criteria</b>	<b>Value</b>
Overall Protection of Human Health and the Environment	Yes
Compliance with ARARs	Yes
Long-Term Effectiveness and Permanence	5
Reduction in Toxicity, Mobility and Volume Through Treatment	4
Short-term Effectiveness	4
Implementability	2
Cost (present value, millions of dollars)	\$11

Overall Protection of Human Health and the Environment. Activities to be conducted under this alternative are adequately protective of human health. Extraction.

treatment and reinjection of contaminated groundwater will reduce the mass of contaminants present within the plume and help to ensure that, if unknown exposure pathways exist or exposure pathways are created in the future, residential risk will be at acceptable levels.

Compliance with ARARs. Alternative 3 would attain chemical-specific groundwater ARARs in approximately 8 years. This alternative can be implemented in a manner that complies with location- and action-specific ARARs (Appendix A, Tables 4 through 6).

Long-Term Effectiveness and Permanence. Activated carbon is capable of effectively adsorbing EDB and CCl<sub>4</sub>. However, even at 600 gpm, an FS-29 plume treatment system, in conjunction with a containment system treating the CS-21 plume, a small portion of the plume mass (4 percent) will escape capture, according to modeling scenarios. Discontinuous contaminant distribution, coupled with a basal layer of silty clay and interspersed silty sand and silt layers, create a situation in which pumping is less effective at capturing plume contaminants than it would be in other lithologies. Figure 6-4 shows modeled plume capture for this alternative and modeled incidental FS-29 plume capture by the proposed CS-21 treatment system.

As discussed under Alternative 1, hydrolysis and dispersion will have a significant effect on reducing contaminant concentrations in the plume. Contamination that is captured and treated by the ETR system is permanently removed from the environment. The concentration of contaminants in captured groundwater would be reduced to background levels. In combination with natural processes, treatment proposed under this alternative is expected to reduce contaminant concentrations within the current plume to background levels. No unacceptable human health or ecological impacts from uncaptured contamination are anticipated. Hydrolysis and dispersion are also irreversible phenomena. No impacts to private or municipal wells are anticipated from uncaptured contamination since residents downgradient of the FS-29 plume are connected to municipal water supplies, and the only known potential water supply well site (the Ballymeade well near 69MW1540) is outside the plume.

Groundwater extraction within the FS-29 plume would pull FS-29 plume contaminants further away from this potential well site. Negative socioeconomic impacts will result from construction activities to be conducted as part of this alternative. These impacts may or may not be larger than the negative impacts caused by the plume itself.

Reduction of Toxicity, Mobility, or Volume Through Treatment. An extraction, treatment and reinjection system designed to treat the FS-29 plume would be required to extract approximately 0.160 kilograms of EDB from 1.2 billion gallons of contaminated water. Because of irregularities and discontinuities in plume geometry and dilution by radial flow to the extraction wells, treatment plant influent concentrations may be below regulatory standards. This is especially true considering the two parallel lobes of contamination and the uncontaminated water that lies between the lobes. Because contaminant concentrations within the plume are low (ranging from 0.02 µg/L to 0.108 µg/L of EDB), plant influent concentrations will likely be below the MMCL.

The treatment systems for the FS-12 and FS-28 plumes also treat EDB-contaminated groundwater. Since each system start-up, the EDB concentrations in influent at both of these plants have decreased an order of magnitude (Figure 6-5). Given the extremely low initial influent concentration that would be encountered in an FS-29 treatment system, influent concentrations could be below the detection limit within a matter of months.

Because very little contamination exists within this plume (0.160 kilograms of EDB and significantly less CCl<sub>4</sub>), an ETR system will not be very effective at reducing toxicity or future environmental or human health risks when compared to the impacts that natural processes will have on plume contaminants.

Short-term Effectiveness. Implementation of Alternative 3 would involve certain construction impacts on site workers, the community and the environment, but the alternative would be implemented in a manner that would minimize these impacts.

Given the effects of hydrolysis and dispersion, the alternative will be capable of meeting remedial clean-up objectives in approximately 8 years. Modeling indicates that this alternative will not cause unacceptable levels of drawdown or mounding in surface waters.

Implementability. This alternative relies on proven and reliable technologies. There should be little difficulty in obtaining required personnel, equipment and materials. Effective system design will rely on sophisticated modeling and engineering. High levels of iron and manganese have the potential to foul extraction pumps, well screens, and pipelines. Redevelopment of extraction wells, replacement of pumps, and cleaning of pipelines may be required on a regular basis.

Obtaining access for drilling, construction and other activities proposed under this alternative may be difficult. North of Route 151, the plume lies beneath the Crane Wildlife Management Area. South of Route 151, the plume lies beneath a proposed golf course and a residential neighborhood. Permission to construct an aboveground treatment facility within the Crane Wildlife Management Area will be difficult to obtain because the presence of the building would prevent hunting in the area immediately surrounding the building. Currently, hunting is forbidden within a radius of 500 feet of a permanent structure. Other buildings within the Crane Wildlife Management Area have suffered vandalism in recent years, and this may be a problem during construction and operations. Construction of the system, either near the proposed golf course or in the residential neighborhood, will likely face opposition due to the perceived negative impact that the presence of the system will have on property values and the disruptive effects of construction. The location of the treatment plant proposed under this alternative, between Route 28 and the residential community, would be on undeveloped land.

Cost. The total installed cost (TIC) for this alternative is approximately \$6,600,000. Annual operating costs are estimated at \$740,000. The present value of life cycle costs is approximately \$11,000,000. Uncertainty exists in the time required to achieve cleanup standards, and longer remedial times would result in higher costs.



#### **6.2.4 Alternative 7: Extraction, Treatment and Reinjection to Capture the Central Portion of the FS-29 Plume**

This alternative is similar to Alternative 3, except the capture zone of the treatment system is limited to the central portion of the plume (Figure 6-2). The goal of the alternative would be 100 percent capture of the central portion of the plume. This alternative consists of active remediation with an ETR system, continued monitoring of the plume, operational monitoring, ecological monitoring, and institutional controls.

The treatment system would include extraction wells located along the axis of the plume. Elevated concentrations of iron and manganese will likely necessitate the use of pretreatment. Pretreatment would consist of greensand filtration and the necessary pumps and tanks to backwash the greensand filters. Contaminants of concern would be removed with activated carbon.

Treated water would be returned to the aquifer in an infiltration gallery located to minimize the dispersive effects from treated water. The treatment system could be located on undeveloped land along Route 151. Approximately 3,000 feet of extraction piping and 2,000 feet of reinjection piping would be required.

Alternative 7 would include all monitoring described in Alternative 3. Institutional controls, as presented in Alternative 2, would also be included. A thorough site review would be conducted every five years for as long as plume contaminants remained above statutory standards.

This alternative would require a project execution plan, design report and sampling and analysis plan to be written before implementation. Annual performance monitoring evaluation reports would also be required. These annual reports would detail system operations and monitoring results for the previous year.

Although this alternative calls for the construction of a treatment system specifically for the FS-29 plume, it may also be possible to modify the design objectives for the

proposed CS-21 treatment system to allow for FS-29 plume water to be treated in that treatment plant. Under this option, water would be extracted from the central section of the FS-29 plume and piped to the main CS-21 treatment system. Design of the CS-21 system would be modified to contain sufficient capacity to treat and discharge this water.

This option could also effectively capture this portion of the FS-29 plume. Because no new aboveground facilities are included in this alternative, access may be easier to obtain. However, there are several reasons why this option does not appear to be advantageous at this time: (1) difficulties transporting high iron water to the CS-21 treatment plant, (2) the potential need for pretreatment of FS-29 plume water (CS-21 plume water is less likely to require pretreatment), (3) competition for adsorption sites within the carbon filter may result in higher demand for carbon, and (4) cost for additional piping.<sup>11</sup> Because this option does not appear to be advantageous at this time, this alternative will be evaluated under the assumption that a treatment plant dedicated to FS-29 plume water would be used. However, the use of a combined treatment plant would be considered during remedial design, based on data that are available at that time.

Table 6-5 presents a summary of the evaluation for Alternative 7 according to CERCLA evaluation criteria. A discussion of the evaluation follows.

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<sup>11</sup> Capital costs for a separate treatment system for the FS-29 plume would be essentially equal to the incremental increase in the cost of designing and constructing the CS-21 treatment system to handle FS-29 plume water except that combined treatment requires piping runs that are long enough to bring the water to the CS-21 treatment plant and then return it to an area that would minimize hydraulic impacts on the plumes.

**Table 6-5**  
**Evaluation of Alternative 7: FS-29 Plume**

<b>Evaluation Criteria</b>	<b>Value</b>
Overall Protection of Human Health and the Environment	Yes
Compliance with ARARs	Yes
Long-Term Effectiveness and Permanence	4
Reduction in Toxicity, Mobility and Volume Through Treatment	3
Short-term Effectiveness	4
Implementability	2
Cost (present value, millions of dollars)	\$10

Overall Protection of Human Health and the Environment. This alternative adequately protects human health and the environment. There are no known completed pathways to expose human beings or the environment to concentrations above the MCL or MMCL for EDB or CCl<sub>4</sub>. Although it is possible that private wells exist in the area of the plume, area residents have service connections to public water supplies and numerous efforts have been made to inform residents in the area of groundwater quality problems. Residents with private wells are unlikely to use their wells for drinking water or bathing. The Falmouth Board of Health recently approved Additional regulations in order to minimize and prevent the consumption or use of contaminated water from private wells. This alternative actively removes plume contaminants to help ensure that exposure does not occur in the future.

Compliance with ARARs. Alternative 7 seeks to remediate the central portion of the FS-29 plume by actively treating the contaminated groundwater. In combination with hydrolysis and dispersion, the active treatment addressed by this alternative will eliminate contaminant concentrations above the drinking water standard in approximately 10 years. This alternative would be implemented in a manner that complies with location- and action-specific ARARs (Appendix A, Tables 4 through 6).

Long-Term Effectiveness and Permanence. This alternative is capable of removing plume contaminants so that no recurrence is possible. This alternative is not capable of removing all plume contaminants. Contaminants at the distal portion of the plume

will escape capture. Extraction in the central portion of the plume will capture the highest concentrations of EDB in the plume. It will also capture some CCl<sub>4</sub>, but the highest concentrations of CCl<sub>4</sub> are downgradient of the proposed extraction zone.

Captured contaminants would be removed to background levels. In conjunction with active treatment, natural processes are expected to reduce contaminant concentrations within the current plume to background levels. Human health and environmental impacts from uncaptured contamination are discussed in Overall Protection of Human Health and the Environment. Extraction proposed under this alternative will do little to provide additional protection for the proposed water supply well south of the FS-29 plume. However, this alternative would expedite aquifer restoration. With no extraction, contaminants in the central portion of the plume would continue to pass to the northwest of the proposed well. With the proposed CS-21 plume extraction, contaminants will move even further from the proposed well site. Minor negative socioeconomic impacts are associated with the uncaptured contamination and with construction activities to be implemented under this alternative.

Reduction of Toxicity, Mobility, or Volume Through Treatment. Carbon treatment is capable of reducing the mass of plume contaminants. Residual contamination downgradient of the extraction zone will remain after treatment, but natural processes will degrade and disperse the contamination. Given the extremely low initial influent concentration that would be experienced in an FS-29 treatment system, influent concentrations could be below the detection limit within a matter of months.

Because very little contamination exists within this plume (approximately 0.160 kilograms of EDB and some CCl<sub>4</sub>), an ETR system will not be very effective at reducing toxicity or future environmental or human health risks when compared to the impacts that natural processes will have on plume contaminants.

Short-Term Effectiveness. Implementation of this alternative involves certain construction impacts on the local community and site workers, but construction activities would be conducted so as to minimize these impacts. When combined with

the effects of hydrolysis, dilution and dispersion, this alternative would be capable of meeting remedial objectives within approximately 10 years.

Implementability. In some areas, it may be difficult to gain the property access necessary to implement this alternative. Locations under consideration for extraction wells lie on land that has been proposed for use as a golf course and in a residential community.

Cost. Costs for this alternative are very similar to Alternative 3. The TIC for this alternative is approximately \$6,000,000. Annual operations and maintenance costs would be approximately \$740,000 during treatment system operations. It is anticipated that the treatment system for this alternative would run for a shorter period of time than the treatment system in Alternative 3. However, plume monitoring would have to run for a longer period of time to track uncaptured contamination. The present worth of life cycle costs for this alternative are estimated to be approximately \$10,000,000. Uncertainty exists in the time required to achieve cleanup standards, and longer remedial times would result in higher costs.

### **6.2.5 Comparison of Alternatives**

Table 6-6 compares the four alternatives according to the Remedial Alternative Evaluation System presented in Section 4.2.

**Table 6-6  
FS-29 Plume Comparison of Alternatives**

<b>Evaluation Criteria</b>	<b>Alternative 1: No Remedial Action with Long-Term Monitoring</b>	<b>Alternative 2: Institutional and Engineering Controls</b>	<b>Alternative 3: ETR for Plume Capture</b>	<b>Alternative 7: ETR to Capture the Central Portion of the FS-29 Plume</b>
Overall Protection of Human Health and the Environment	No	Yes	Yes	Yes
Compliance with ARARs	Yes	Yes	Yes	Yes
Long-Term Effectiveness and Permanence	3	3	5	4
Reduction of Toxicity, Mobility or Volume through Treatment	1	2*	4	3
Short-Term Effectiveness	5	5	4	4
Implementability	4	3	2	2
Cost (present value in millions)	\$0.97	\$3.1	\$11	\$10

\*Alternative 2 includes wellhead treatment for the proposed Ballymeade water supply well, if needed.

Threshold Criteria. Alternative 1 (no remedial action with long-term monitoring) does not adequately protect human health. Alternative 2 (institutional and engineering controls), Alternative 3 (ETR for plume capture) and Alternative 7 (ETR to capture the central portion of the FS-29 plume) all comply with threshold criteria. All three of these alternatives adequately protect human health and the environment. Currently, no known residential exposure pathways exist for contamination. Alternatives 3 and 7 take additional steps to reduce the mass of contamination present within the aquifer. Alternatives 3 and 7 would reduce the time that contaminants remain in the aquifer at concentrations above cleanup standards.

Alternatives 1, 2, 3, and 7 comply with ARARs. All four alternatives would reduce the levels of groundwater contaminants to below cleanup standards in a reasonable time (Table 6-7).

**Table 6-7**  
**Comparison of Alternatives: Approximate Cleanup Times**

	<b>Alternative 1: No Remedial Action with Long-Term Monitoring</b>	<b>Alternative 2: Institutional and Engineering Controls</b>	<b>Alternative 3: ETR for Plume Capture**</b>	<b>Alternative 7: ETR to Capture the Central Portion of the FS-29 Plume***</b>
CCl <sub>4</sub>	5 µg/L MCL will be met in 10 years	5 µg/L MCL will be met in 10 years	5 µg/L MCL will be met in 5 years	5 µg/L MCL will be met in 10 years
EDB	0.02 µg/L MMCL will be met in 13 to 17 years*	0.02 µg/L MMCL will be met in 13 to 17 years*	0.02 µg/L MMCL will be met in 8 years	0.02 µg/L MMCL will be met in 10 years

\*These times are from the date of data acquisition.

\*\*Advective flow modeling indicates that 28 years would be required for Alternative 3 to restore the plume, but this ignores hydrolysis and dispersion.

\*\*\*Under Alternative 7, contaminant concentrations in the central portion of the plume would be below MCLs and MMCLs in less than eight years.

The restoration times presented for all FS-29 alternatives are ultimately based on the hydrolysis half-life of EDB. The restoration time for Alternatives 1 and 2 for the FS-29 plume (13 to 17 years) was developed based on the maximum contaminant concentration detected and an EDB degradation half-life of 5.4 to 7.2 years. Slower degradation of EDB would result in longer times until restoration. No attempt has been made to account for capture by the proposed CS-21 treatment system under these alternatives. More importantly, the effects of dispersion, which will shorten restoration times, were not accounted for. The eight-year restoration time frame presented for Alternative 3 is a qualitative estimate of the interaction of the extraction to take place under Alternative 3 and hydrolysis and dispersion. The estimated restoration time under Alternative 7 is based on a similar qualitative estimate.

Appendix A, Tables 4 through 6, provides a comparison of each alternative's ability to comply with chemical-, location- and action-specific ARARs.

Primary Balancing Criteria. Alternative 3 provides the most effective capture and removal of FS-29 plume contaminants, with approximately 96 percent of plume mass captured. Alternative 7 includes less aggressive capture and allows the distal portion of the plume to escape capture. Despite model predictions, the actual influent into the

treatment systems proposed under these alternatives may contain no detectable concentrations of contaminants of concern soon after system start-up. Neither Alternative 1 or Alternative 2 actively removes contaminants. Natural attenuation processes are expected to be significant regardless of which remedial alternative is implemented.

Because of negative environmental impacts associated with treatment system construction, Alternatives 1 and 2 provide slightly greater short-term effectiveness. Alternative 1 is the most easily implemented. Each of the other three alternatives include institutional controls. As described in Section 6.2.2, the Falmouth Board of Health recently approved additional regulations in order to minimize and prevent the consumption or use of contaminated water from private wells. AFCEE will continue to work with the Board of Health to make sure that the Board of Health has the information needed to make informed decisions regarding well permitting. AFCEE will continue to work with the regulatory agencies and the town of Falmouth to have additional institutional controls established, but AFCEE does not control this process. Access for the construction activities presented under Alternatives 3 and 7 may be difficult to obtain. Additionally, high iron and manganese levels have the potential to cause operational difficulties.

Alternative 1 has the lowest cost (\$970,000). Costs for Alternative 2 (\$3,100,000) are approximately three times higher. Costs for Alternatives 3 (\$11,000,000) and 7 (\$10,000,000) are approximately 10 times as high as for Alternative 1, and three to 3.5 times as high as for Alternative 2. The cost estimates for Alternatives 3 and 7 assume that high metals concentrations present in the plume will require the use of pretreatment, such as greensand filtration.

Costs for Alternatives 3 and 7 are similar because both the construction and operations and maintenance aspects of these two alternatives are so similar. Both alternatives would require approximately two extraction wells, greensand filtration, and a pair of carbon adsorption vessels. Because Alternative 3 would be designed to



capture the entire plume, a more extensive data-gap investigation was included in the estimate. It was estimated that Alternative 3 would require somewhat longer piping runs because of limitations on sighting the treatment plant. Under Alternative 7, the treatment plant would operate for a shorter period of time, but contamination initially downgradient of the extraction wells would result in a longer monitoring period.

The accuracy of lifecycle cost estimates are directly linked to the accuracy of the estimate of time required to reach MCLs and MMCLs. If hydrolysis occurs more slowly than is currently estimated, costs for all alternatives will increase. Dispersion, which was not factored into the time estimates, will tend to reduce the costs for all alternatives. Because of their high annual costs, the lifecycle costs of Alternatives 3 and 7 will be influenced more strongly if remedial times prove significantly longer or shorter than estimated.

The cost estimates presented are based on reducing contaminant concentrations below the MCL and MMCL. Additional work that may be required under steps 2 or 3 of the three-step process (Section 4.1) is not included in the cost estimates.

The National Contingency Plan requires not only that a selected alternative comply with threshold criteria, but also that it be cost effective (40 CFR 300.430(f)(1)(ii)(D)). Overall effectiveness is determined by evaluating the following criteria: long-term effectiveness and permanence; reduction of toxicity, mobility or volume through treatment; and short-term effectiveness. "Overall effectiveness is then compared to cost to ensure that the remedy is cost effective. A remedy shall be cost effective if its costs are proportional to its overall effectiveness" (40 CFR 300.430(f)(1)(ii)(D)).

Because of the extreme dilution of plume contaminants, the overall effectiveness of an ETR system, such as the system included in Alternatives 3 and 7, in treating this plume would be marginal. The system would be capable of capturing and treating plume contaminants. However, advective flow modeling indicates that at a pumping rate of 600 gpm, 100 percent hydraulic capture of the plume would not be possible. Contaminant concentrations in extracted groundwater can be reduced below

regulatory limits. However, the actual reduction of contaminant mass, and thus toxicity, is limited because the initial contaminant mass is so low and the contamination is so dispersed. For comparison, the FS-12 treatment system removed an average of approximately 0.10 kilograms of EDB from the aquifer per day during its first year of operation by treating 772 gpm. A similarly sized plant would require years to capture the 1.16 billion gallon volume of the FS-29 plume in order to remove the roughly 0.160 kilograms of EDB present.

When overall effectiveness is compared to the estimated system life cycle cost, it is evident that these alternatives are not cost effective as envisioned by the National Contingency Plan. The cost – \$10,000,000 (Alternative 7) to \$11,000,000 (Alternative 3) – is a considerable amount to spend to remove 0.160 kilograms of EDB from the aquifer when no known exposure pathways exist and there is significant cause to believe that contamination concentrations will be reduced below regulatory standards within a relatively short time.

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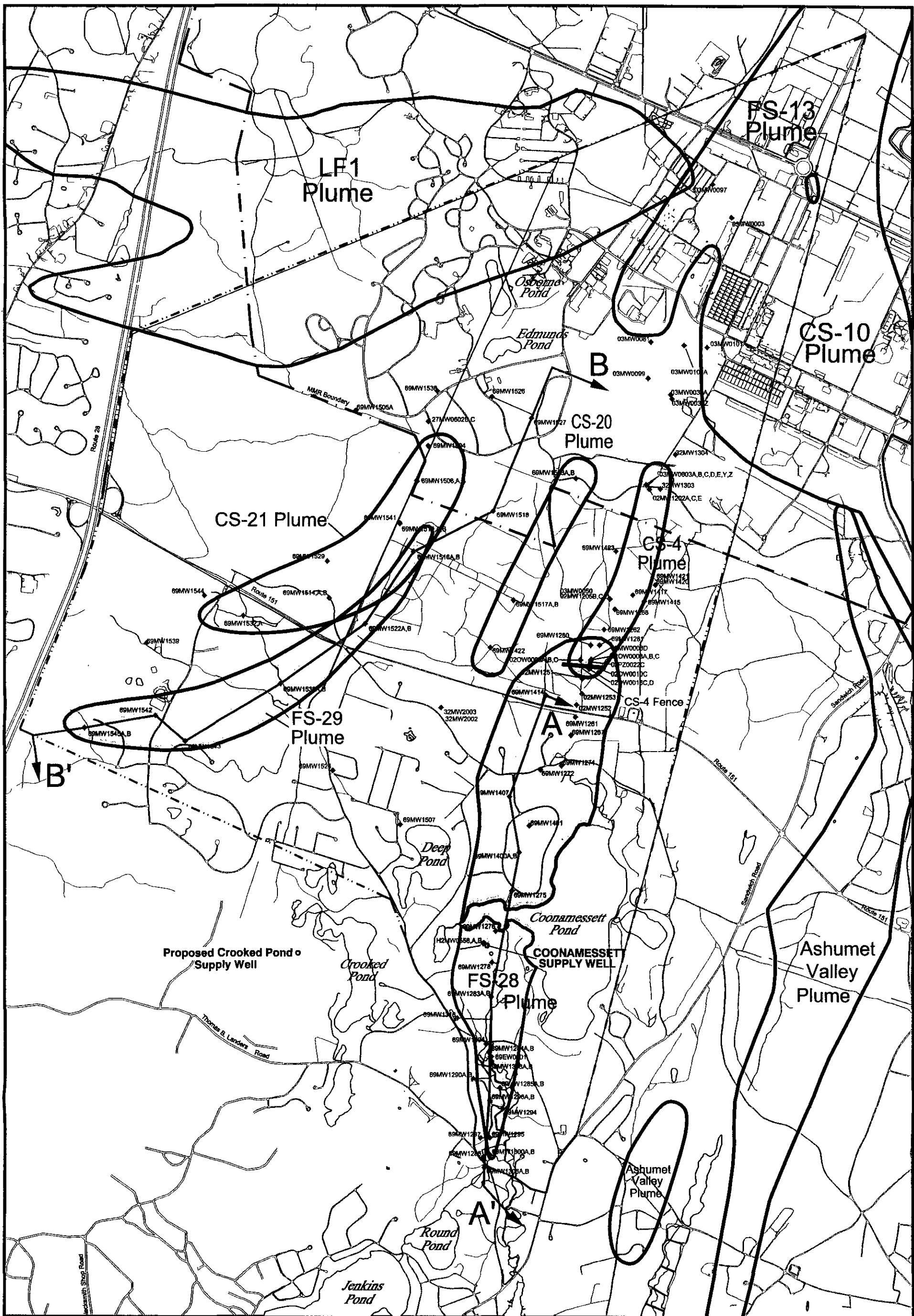
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## FIGURES



# Legend

- Monitoring Well
- Extraction Well
- SWOU Boundary



Public Water  
Supply Well



MMR Boundary



Plume Contour  
(TCE, PCE MCL = 5.0 µg/L)



Cross-Section Lines

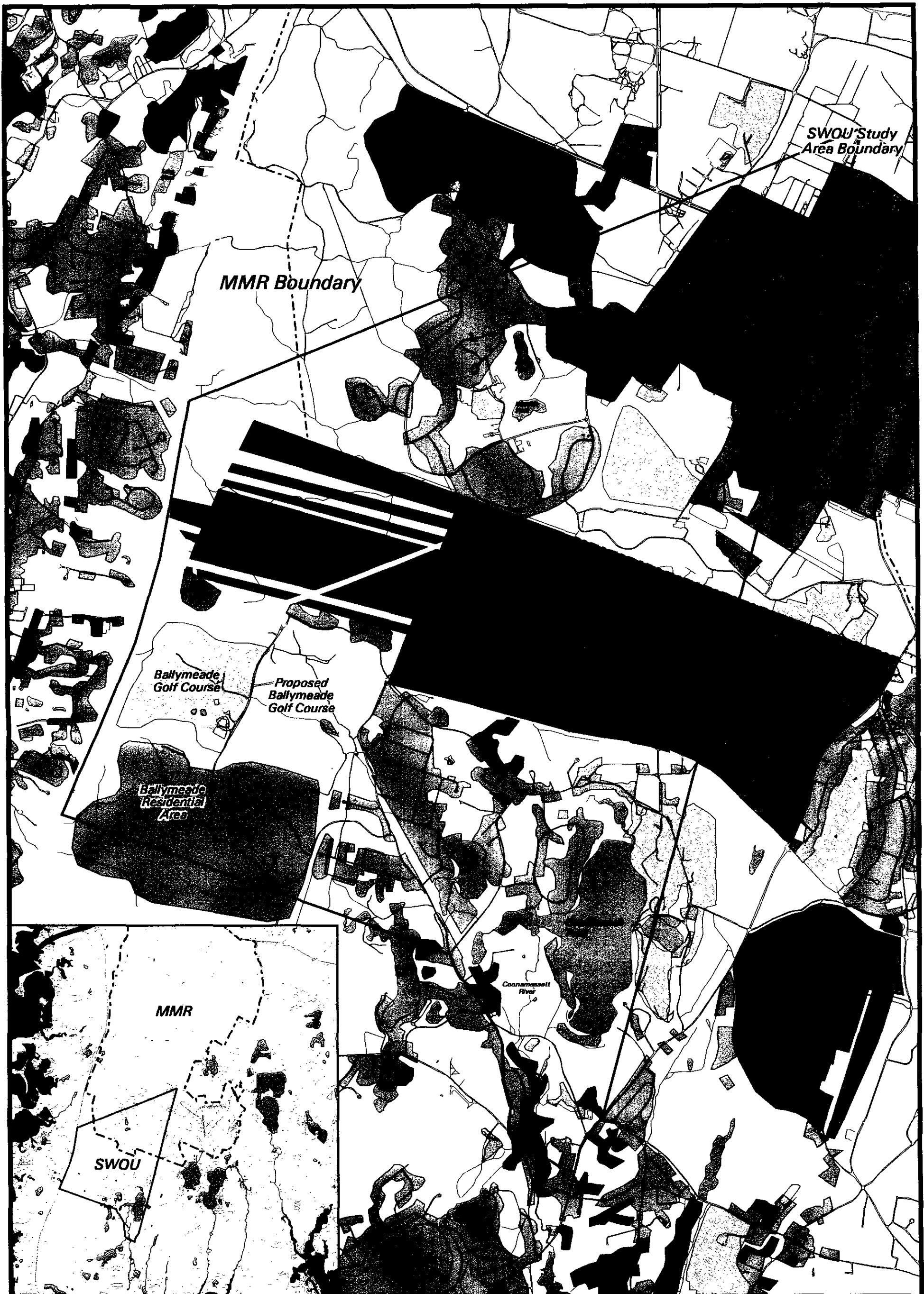


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## Contaminant Cross-Section Plan

Massachusetts Military Reservation  
Cape Cod, Massachusetts

10/26/99 sr File...FS28-29FS-1.dwg Figure 1-1



# Legend

- |  |                               |  |                                |
|--|-------------------------------|--|--------------------------------|
|  | Agricultural Areas            |  | Waste Disposal Areas           |
|  | Recreational Areas            |  | National Cemetery              |
|  | Residential Areas             |  | Crane Wildlife Management Area |
|  | Commercial & Industrial Areas |  |                                |

Note: All uncolored areas are open space

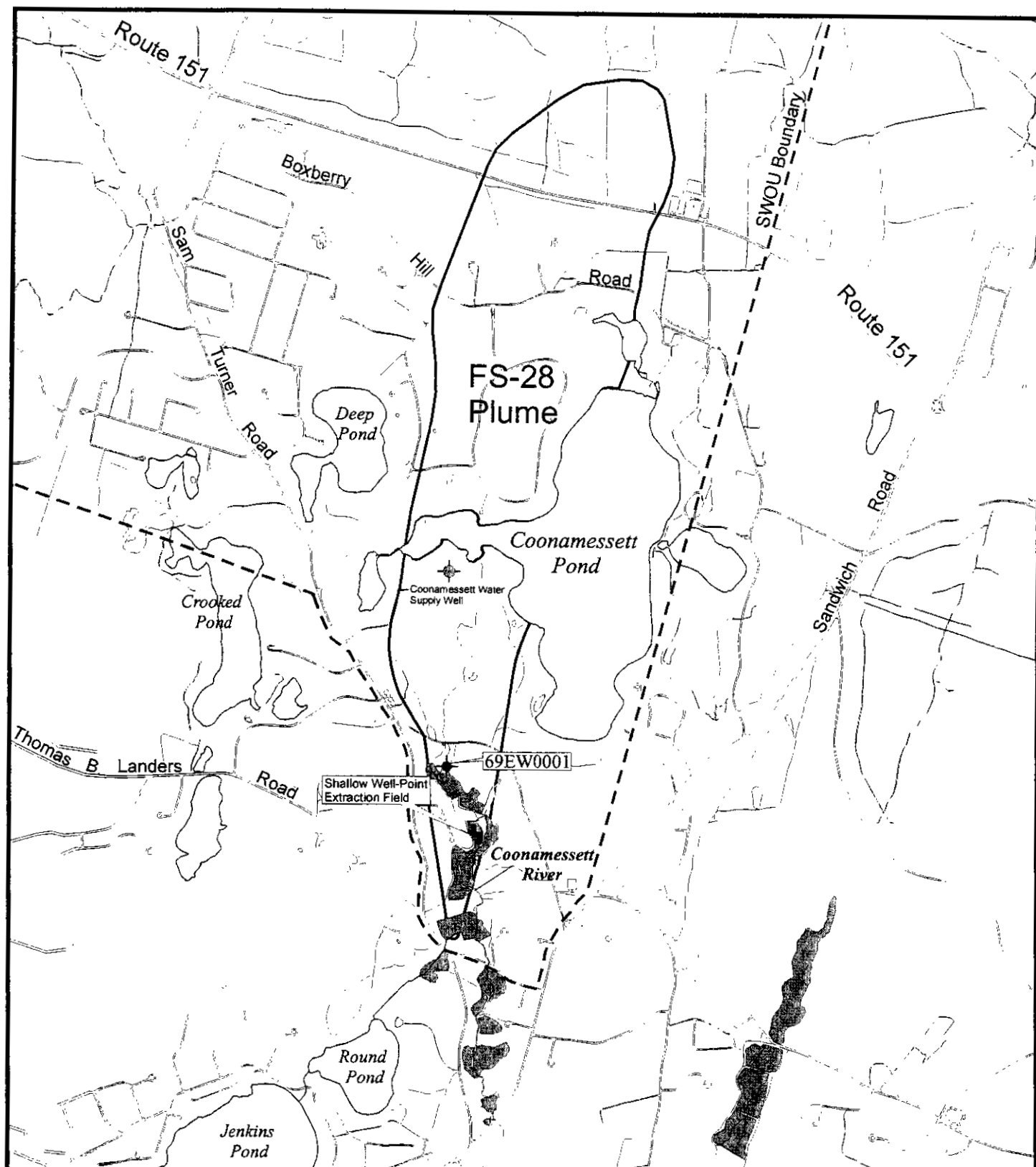
0 2200'  
Scale 1:26400



JACOBS ENGINEERING

## Geographic Features and Current Land Use Patterns

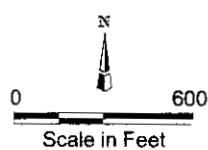
Massachusetts Military Reservation  
Cape Cod, Massachusetts



### Legend

- Plume Contour (EDB MCL 0.02 µg/L)
- SWOU Boundary
- Pond
- Bog
- Shallow Well-Point Field

Existing Extraction Well



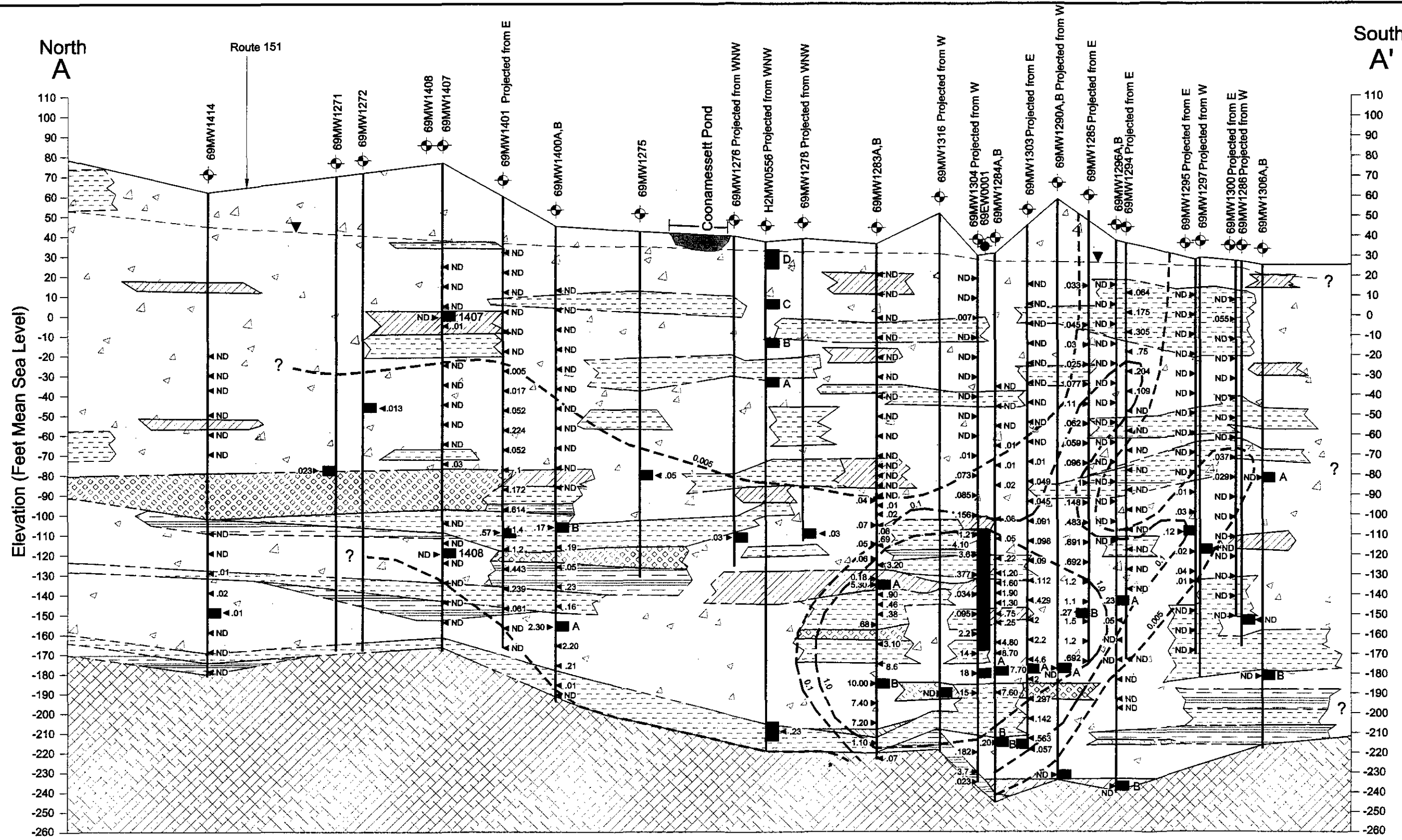
JACOBS ENGINEERING

### The Existing FS-28 Extraction, Treatment, and Discharge System

Massachusetts Military Reservation  
Cape Cod, Massachusetts

10/26/99 sr File: FS28-29FS-1.cdr

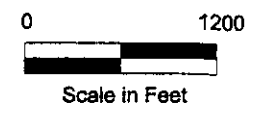
Figure 1-3



**Legend**

- ▲--- Water Table
- Monitoring Well
- ⊗ Extraction Well
- Well Screen ID
- EDB Isoconcentration Contours
- ND Not Detected
- ◀ 0.68 EDB Concentration in µg/L

- Sand
- Silt
- Silty Sand
- Silty Clay
- Gravel
- Bedrock



**JE** JACOBS ENGINEERING

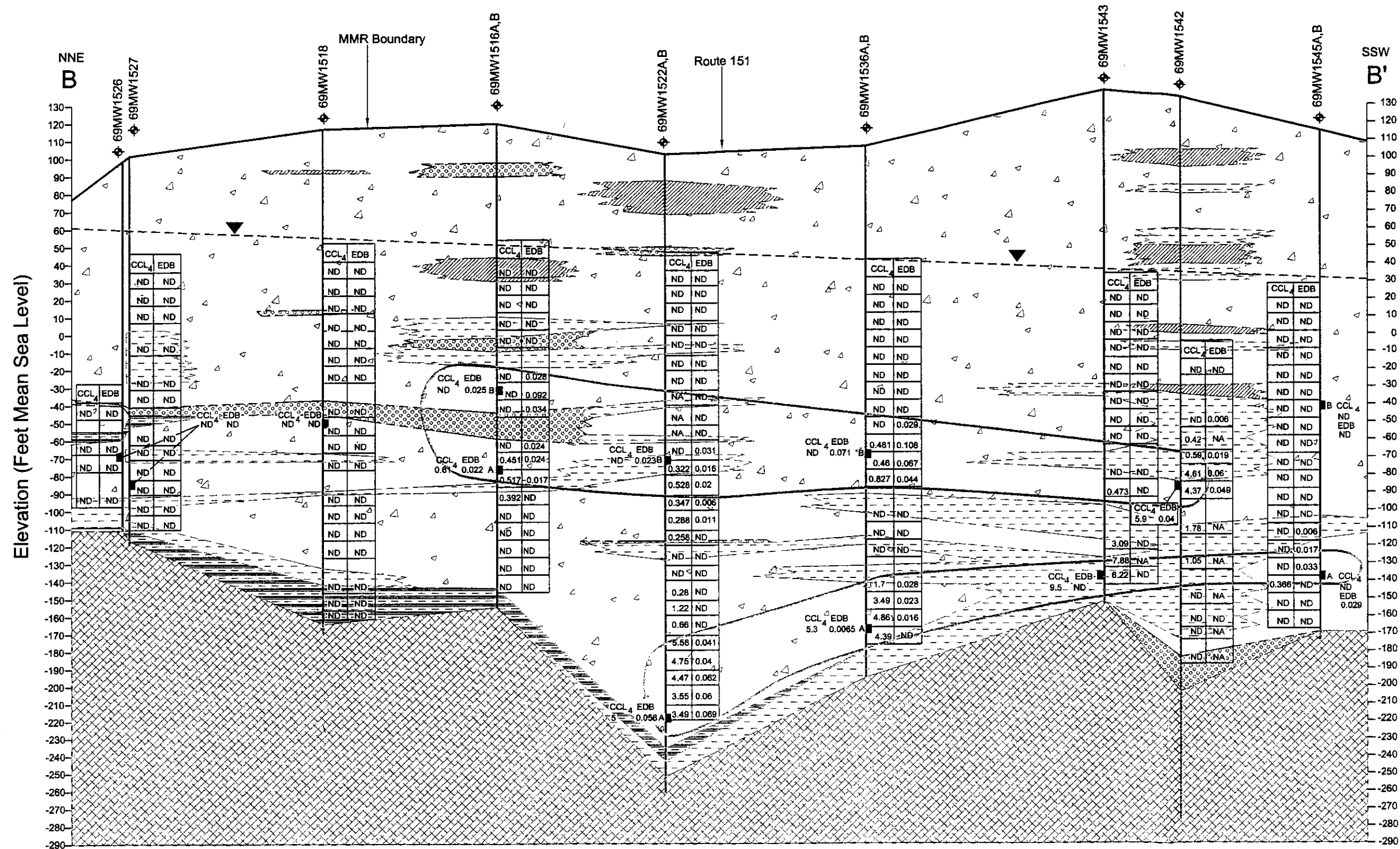
**FS-28 Plume  
Cross-Section A-A'**

Massachusetts Military Reservation  
Cape Cod, Massachusetts

10/27/99 sr File...FS28-28FS-2.dwg

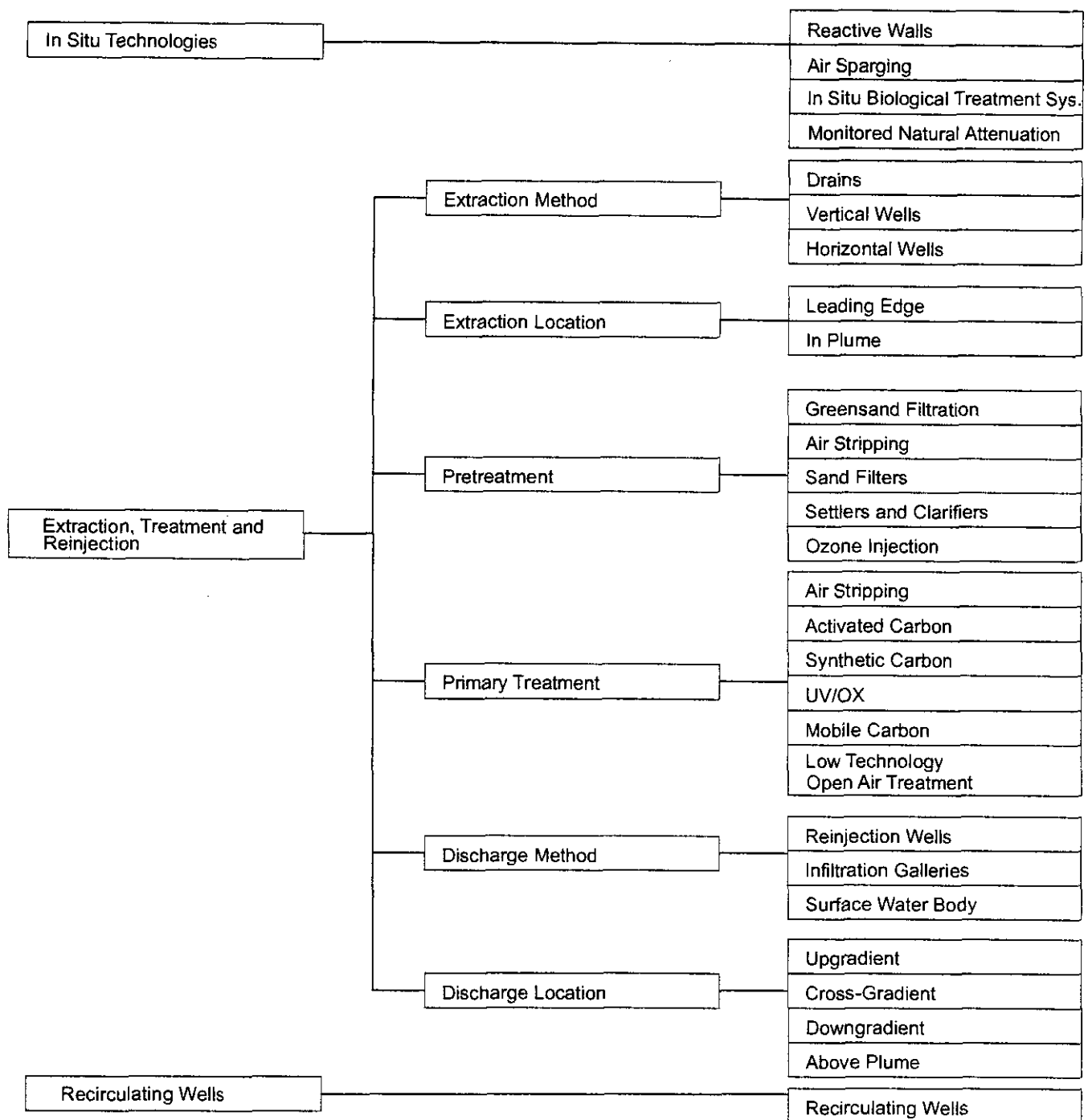
Figure 1-4





## REMEDIAL TECHNOLOGY GROUP

## PROCESS OPTIONS



UV/OX = ultraviolet/oxidation



JACOBS ENGINEERING

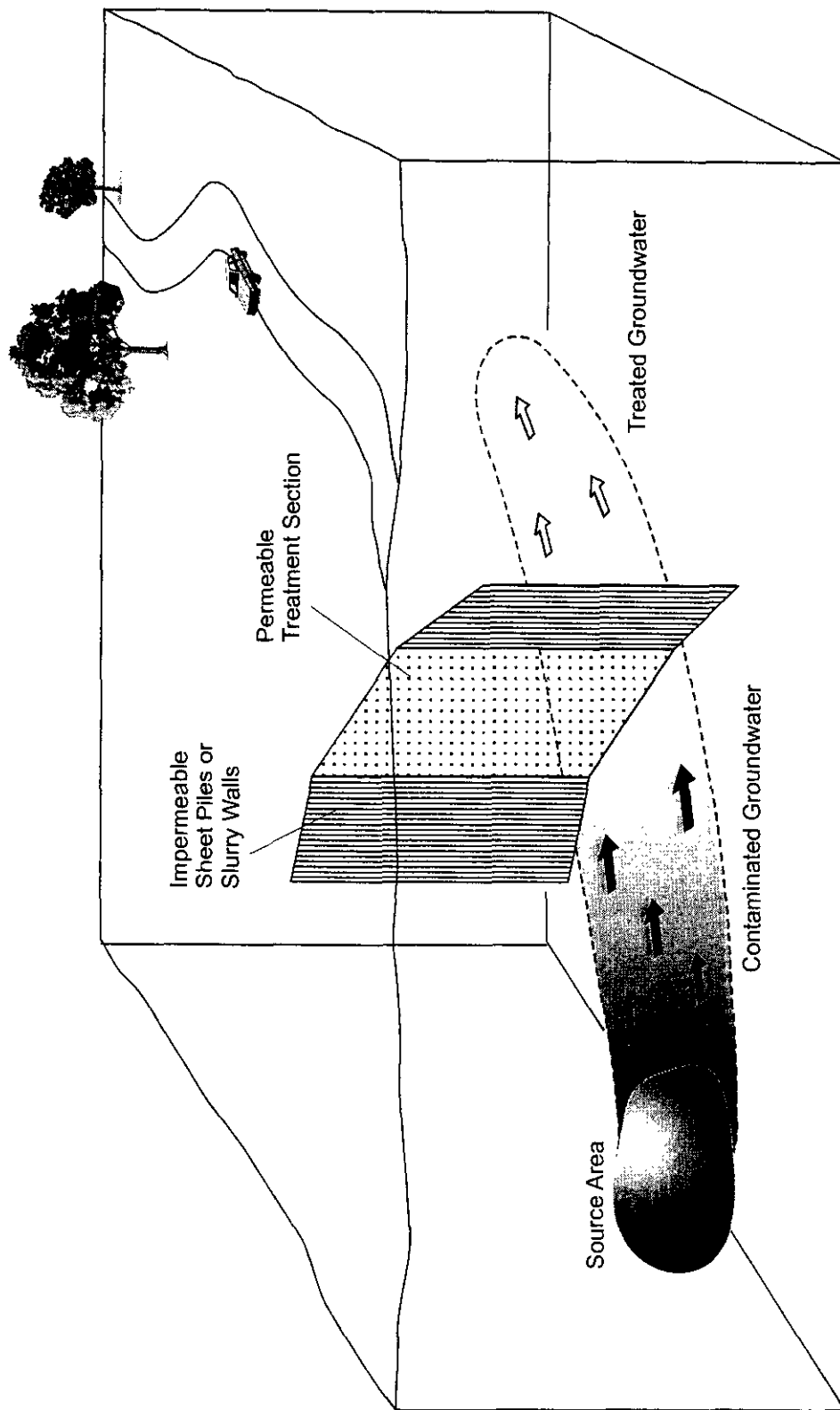
### Potentially Applicable Technologies

Massachusetts Military Reservation  
Cape Cod, Massachusetts

6/29/99 sr File: FS28-GF-5.cdr

Figure 3-1





Funnel and Gate System



JACOBS ENGINEERING

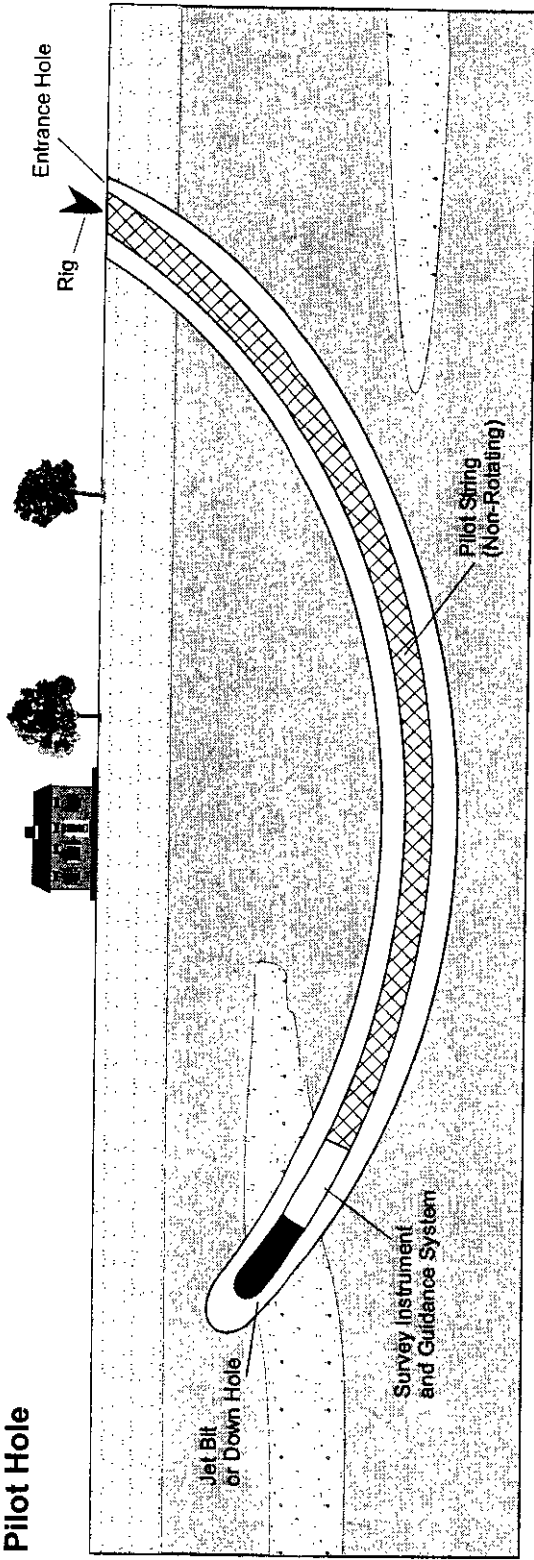
## Schematic of Permeable Treatment Wall

Massachusetts Military Reservation  
Cape Cod, Massachusetts

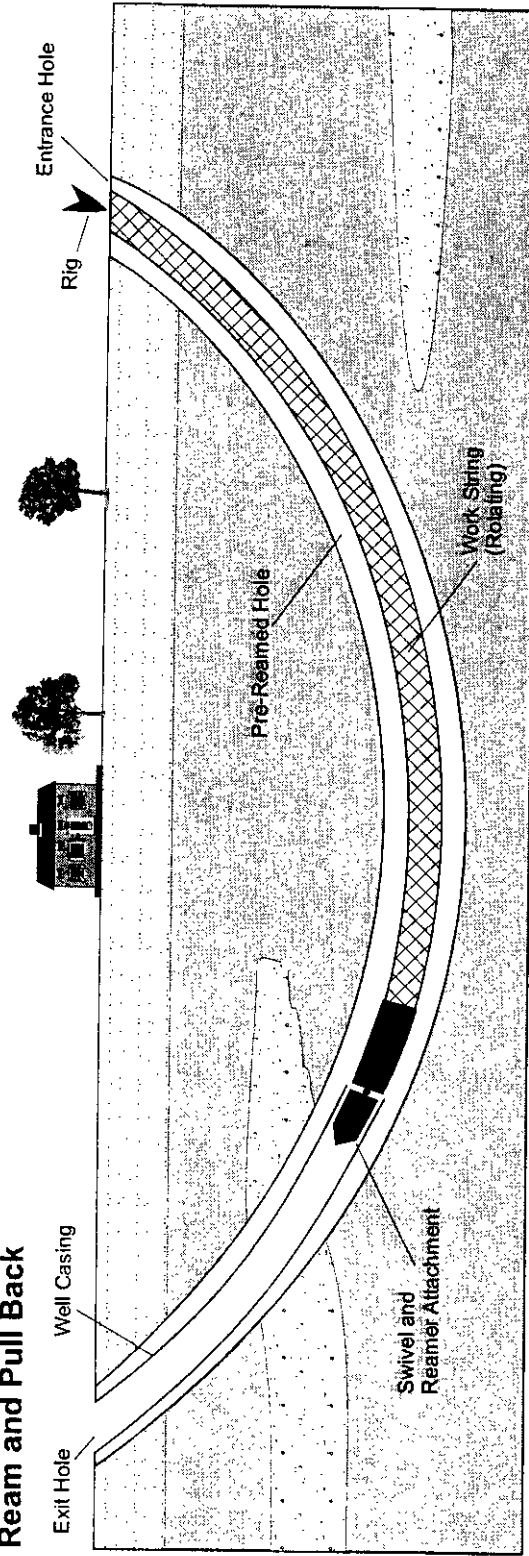
6/21/99 SR File: FS28-GF.6.cdr

Figure 3-2

## Pilot Hole



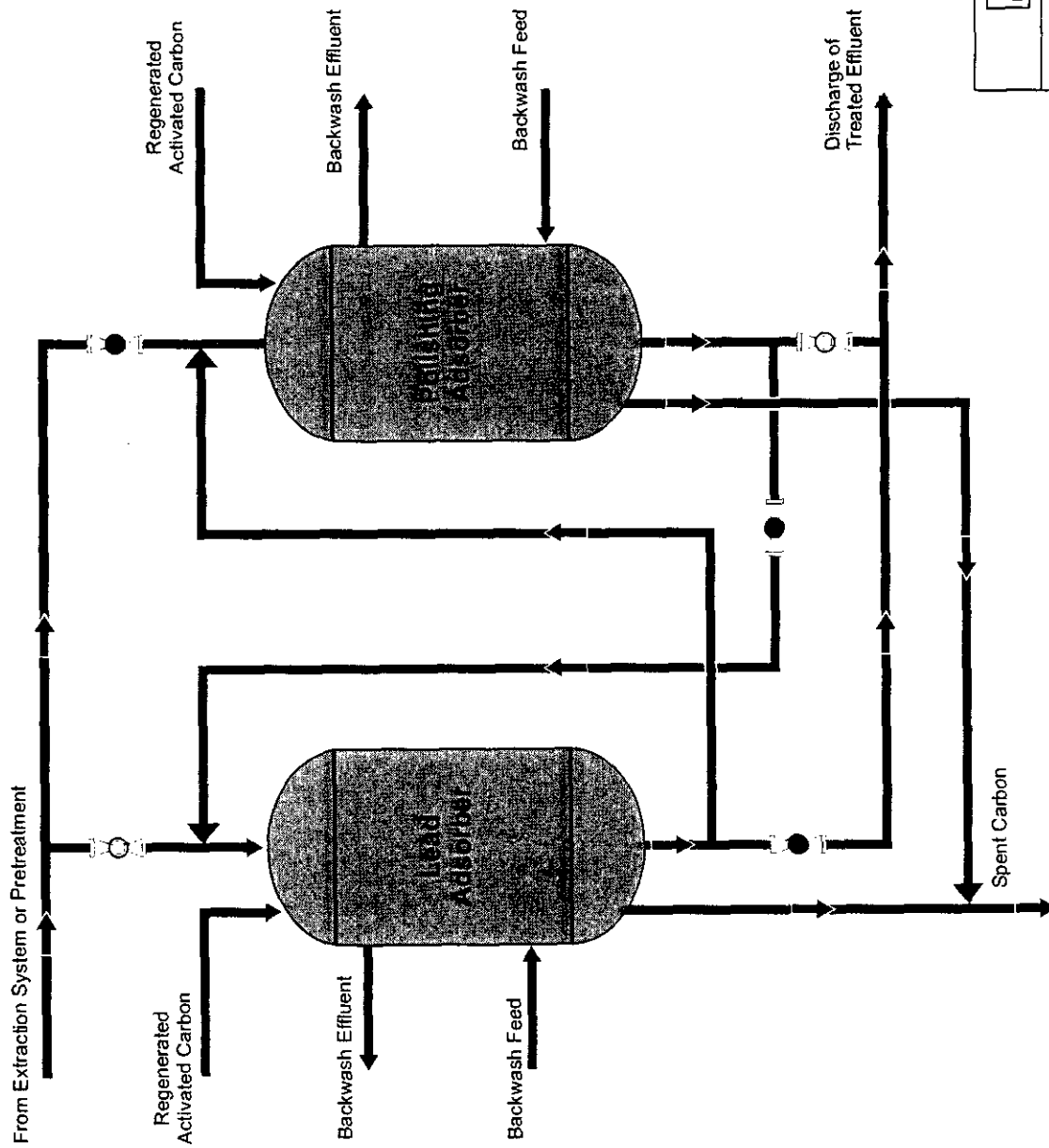
## Ream and Pull Back



JACOBS ENGINEERING


## Schematic of Horizontal Well Installation

Massachusetts Military Reservation  
Cape Cod, Massachusetts



# Legend

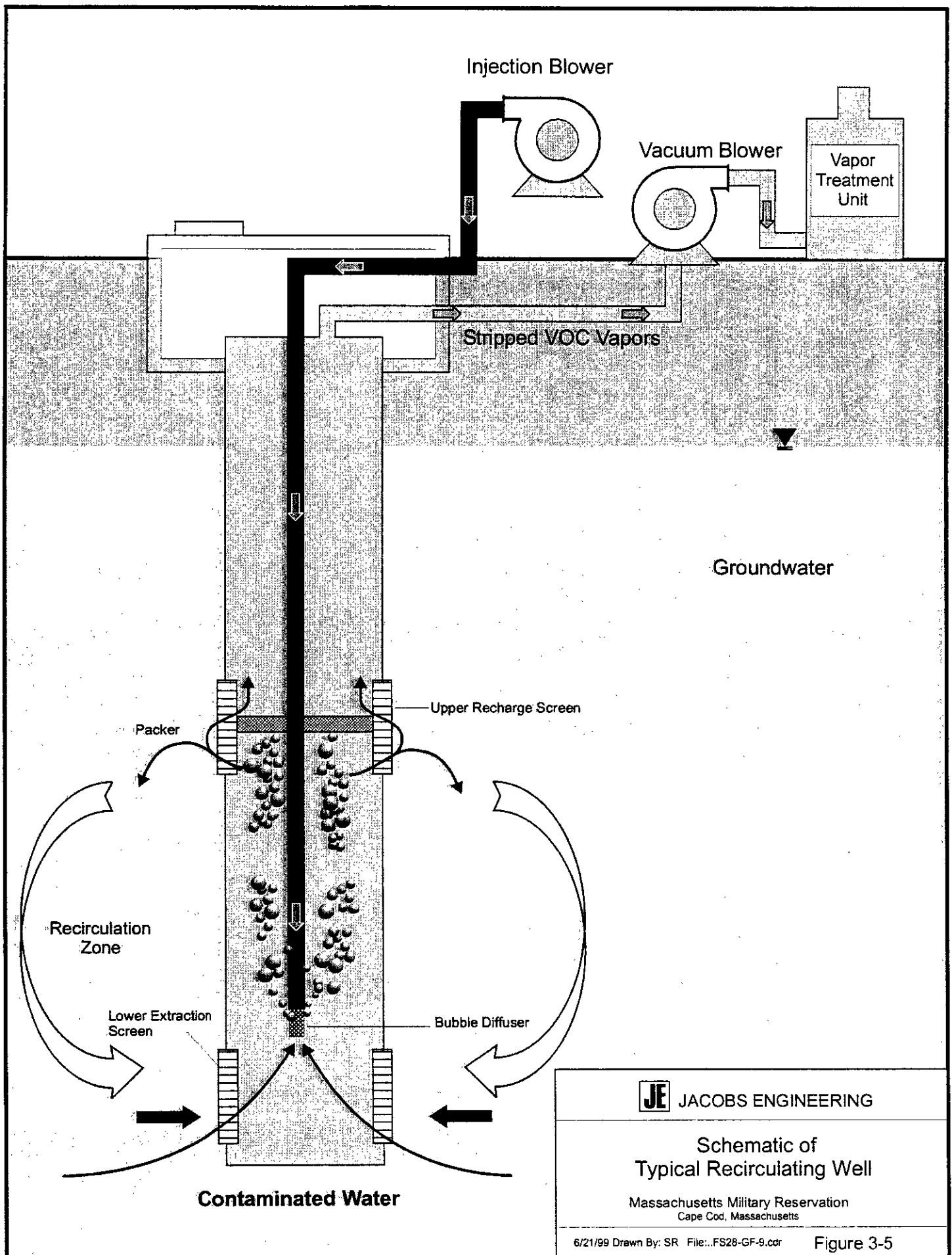
- Valve Closed
- Valve Open


**JACOBS ENGINEERING**

**Two Vessel Granular  
Carbon Adsorption System**  
 Massachusetts Military Reservation  
 Cape Cod, Massachusetts

6/28/99 Job File: FS28-GF-8.cdr

Figure 3-4



**REMEDIAL TECHNOLOGY GROUP**

**PROCESS OPTIONS**

**EFFECTIVENESS**

**IMPLEMENTABILITY**

**COST**

In Situ Technologies

Reactive Walls  
Air Sparging  
In-Situ Biological Treatment Sys.  
Monitored Natural Attenuation

Effective and reliable  
Not effective on all components  
Anaerobic systems may be effective  
Not effective

Never implemented on this scale  
Unsuitable geology  
Unacceptable environmental impact  
Readily implemented

Very high capital. Low O&M  
Moderate capital. Low O&M  
Low capital. Low O&M  
Low capital. Low O&M

Extraction Method

Drains  
Vertical Wells  
Horizontal Wells

Effective and reliable  
Effective and reliable  
Effective and reliable

Cannot be implemented at required depths  
Readily implemented  
Cannot be implemented at required depths

Low capital. Low O&M  
Moderate capital. Moderate O&M  
Very high capital. Moderate O&M

Extraction Location

Leading Edge  
In Plume

Effective  
Effective

Readily implemented  
Readily implemented

N/A  
N/A

Pretreatment

Greensand Filtration  
Air Stripping  
Sand Filters  
Settlers and Clarifiers  
Ozone Injection

Effective and reliable  
Not effective on all components  
Less effective than greensand filters  
Effective and reliable  
Low at expected influent concentrations

Readily implemented  
Readily implemented  
Readily implemented  
Readily implemented  
Readily implemented

Moderate capital. Low O&M  
Low capital. High O&M  
Moderate capital. Low O&M  
Moderate capital. Low O&M  
Low capital. High O&M

Extraction Treatment  
Reinjection

Primary Treatment

Air Stripping  
Activated Carbon Adsorption  
Synthetic Carbon  
UV/OX  
Mobile Carbon Treatment Sys.  
Low Technology  
Open Air Treatment

Cannot reach non-detect levels  
Effective and reliable  
Questionable  
Cannot reach non-detect levels  
Effective and reliable  
Cannot reach non-detect levels

Readily implemented  
Readily implemented  
Never implemented on this scale  
Readily implemented  
Readily implemented  
Large space requirement

Moderate capital. Moderate O&M  
Moderate capital. Moderate O&M  
Moderate capital. Potentially high O&M  
Moderate capital. High O&M  
Low capital. Moderate O&M  
Moderate capital. Low O&M

Discharge Method

Reinjection Wells  
Infiltration Galleries  
Surface Water Body\*

Effective  
Effective  
Effective

Readily implemented  
Readily implemented  
Significant environmental impact

Moderate capital. Low O&M  
Low capital. Low O&M  
Moderate capital. Low O&M

Discharge Location

Upgradient  
Cross-Gradient  
Downgradient  
Above Plume

Effective  
Effective  
Effective  
Effective

May impact other plumes  
Readily implemented  
Readily implemented  
Readily implemented

N/A  
N/A  
N/A  
N/A

Recirculating Wells

Recirculating Wells

Only with treatment at surface

Readily implemented

High capital. Moderate O&M

Notes: O&M = Operations and maintenance

N/A = Not Applicable

Technologies that are screened out

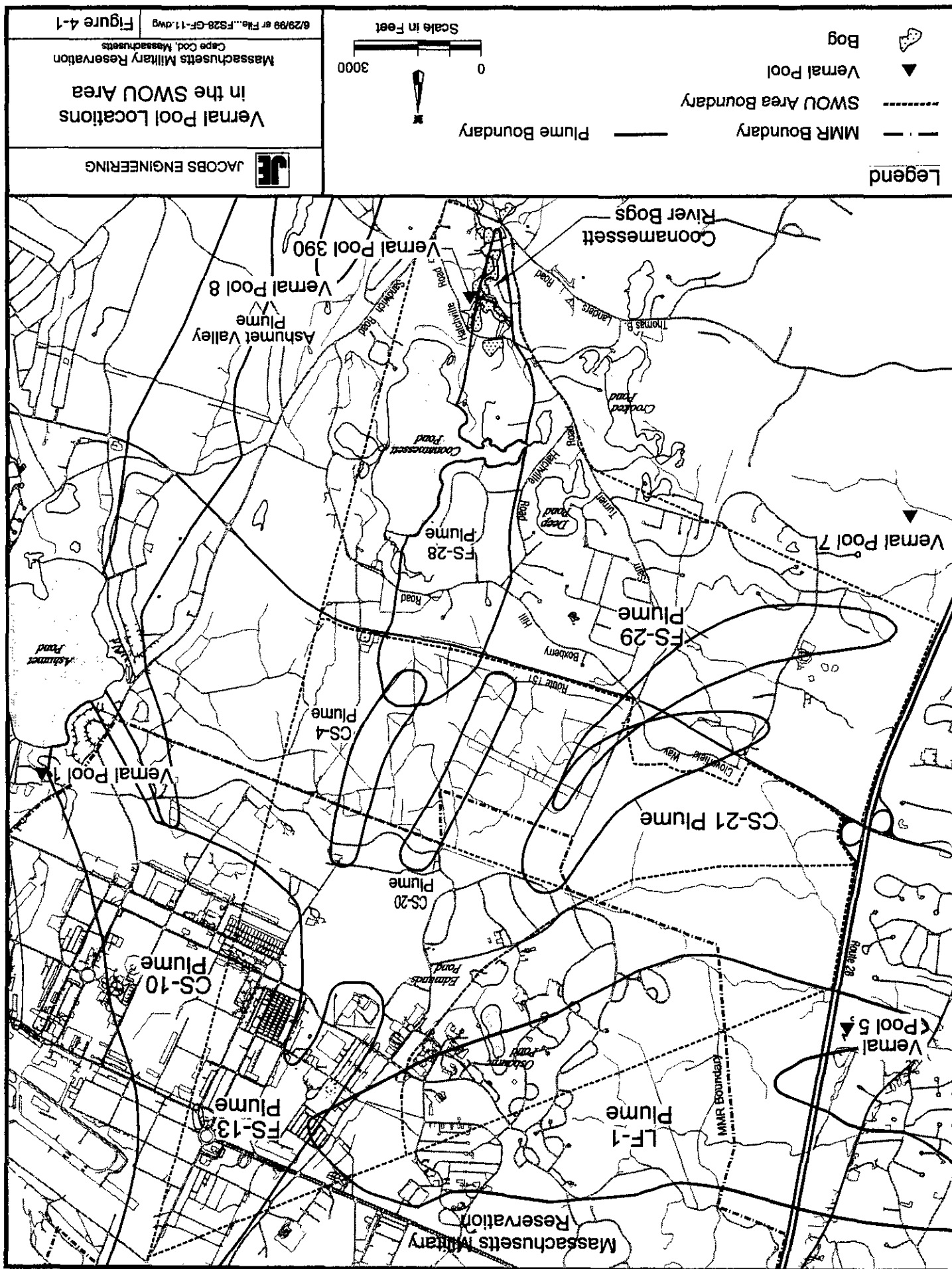
uv/ox = ultraviolet/oxidation

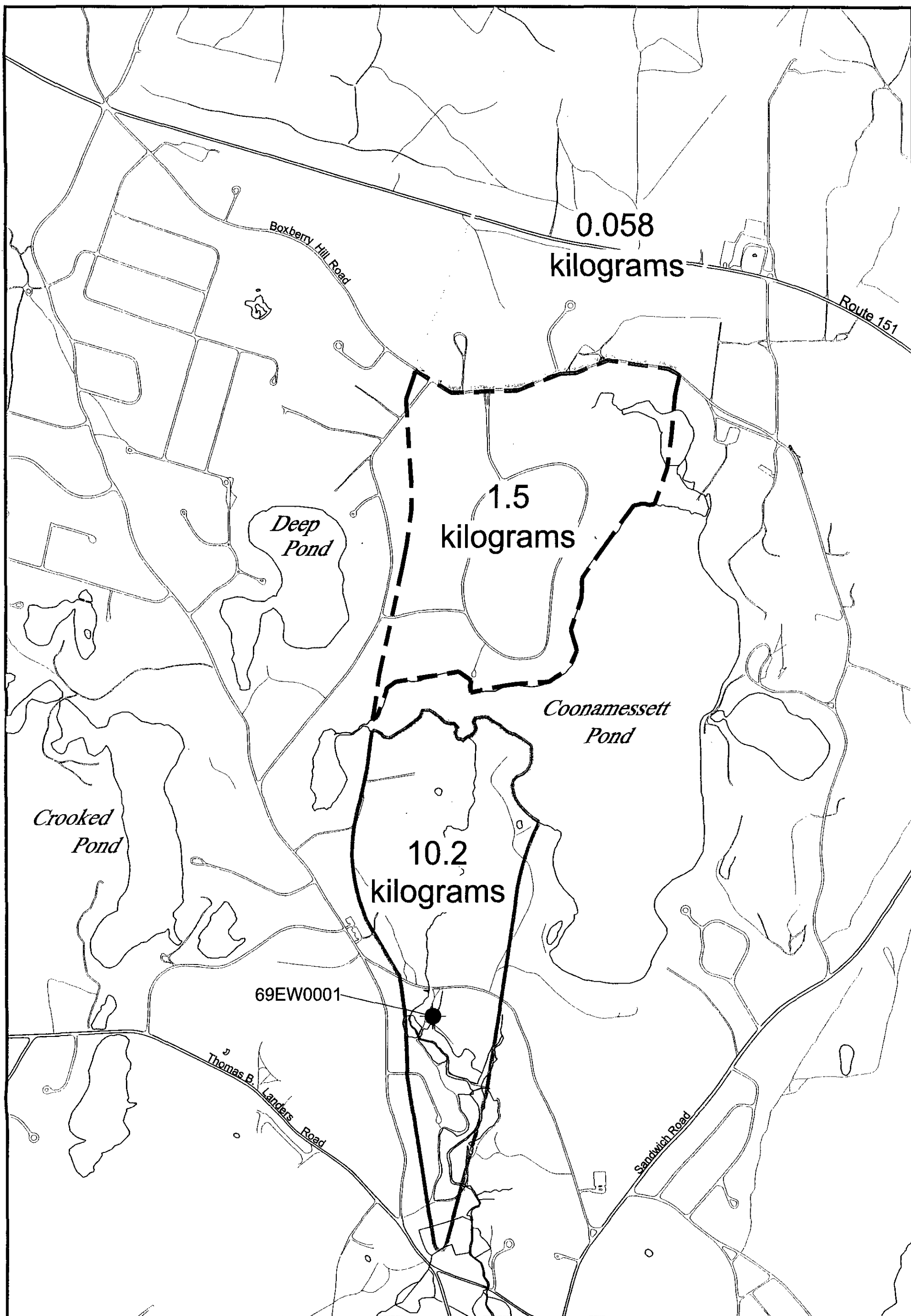
\* The option of surface water body discharge is retained for the FS-28 Plume only.

Technology Screening:  
Results for the  
FS-28 and FS-29 Plumes  
Massachusetts Military Reservation  
Cape Cod, Massachusetts

6/21/99 jbl File: FS28-GF-10.cdr

Figure 3-6





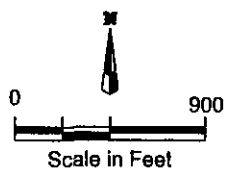
**Legend**

● Extraction Well

FS-28 Plume North of Boxberry Hill Road

FS-28 Plume South of Boxberry Hill Road and North of the Western arm of Coonamessett Pond

FS-28 Plume South of the Western arm of Coonamessett Pond



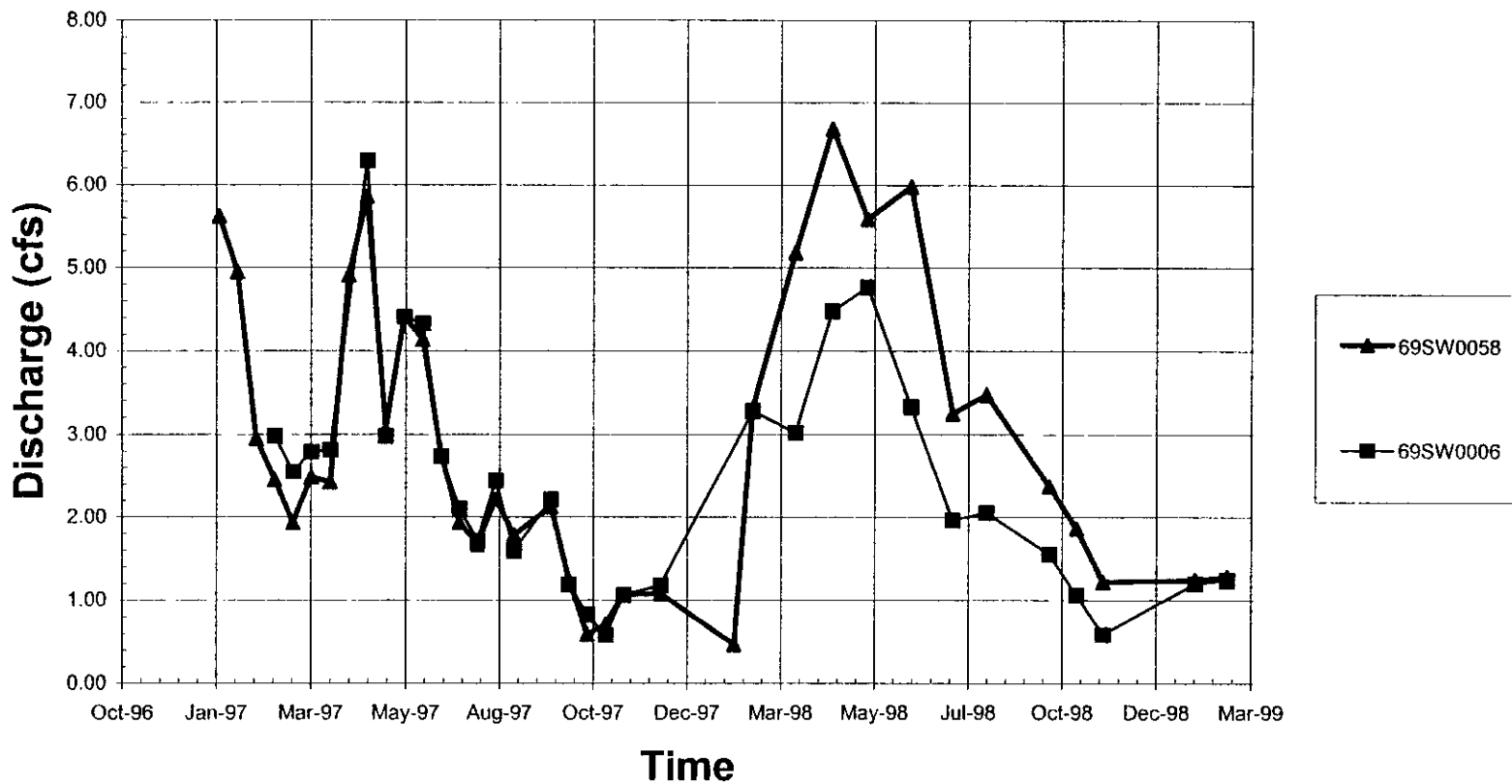
**JE** JACOBS ENGINEERING

**FS-28 Plume  
EDB Mass by Area**

Massachusetts Military Reservation  
Cape Cod, Massachusetts

Note: Figure based on data collected in late 1996 and early 1997 and a few more recent samples collected from monitoring wells near extraction well 69EW0001.

# Coonamessett River Discharge versus Time



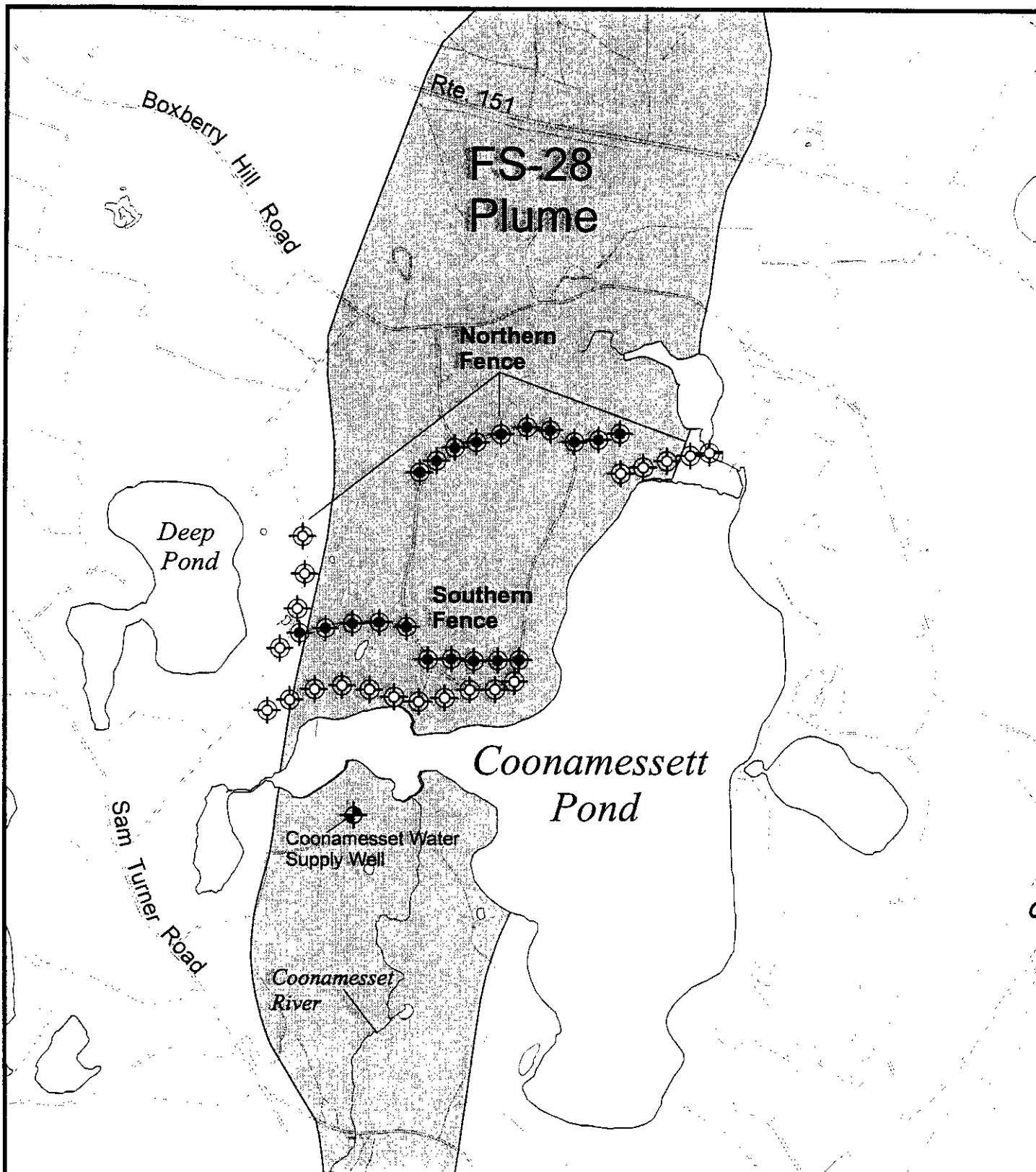
cfs = cubic feet per second

**JE** **JACOBS ENGINEERING**  
**Coonamessett River**  
**Discharge versus Time**  
 Massachusetts Military Reservation  
 Cape Cod, Massachusetts





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Figure 5-2





#### Legend

- |  |  |
|--|--|
|  Plume Boundary |  Extraction Well  |
|  Pond           |  ReInjection Well |

Alternative modeled at 600 gallons per minute

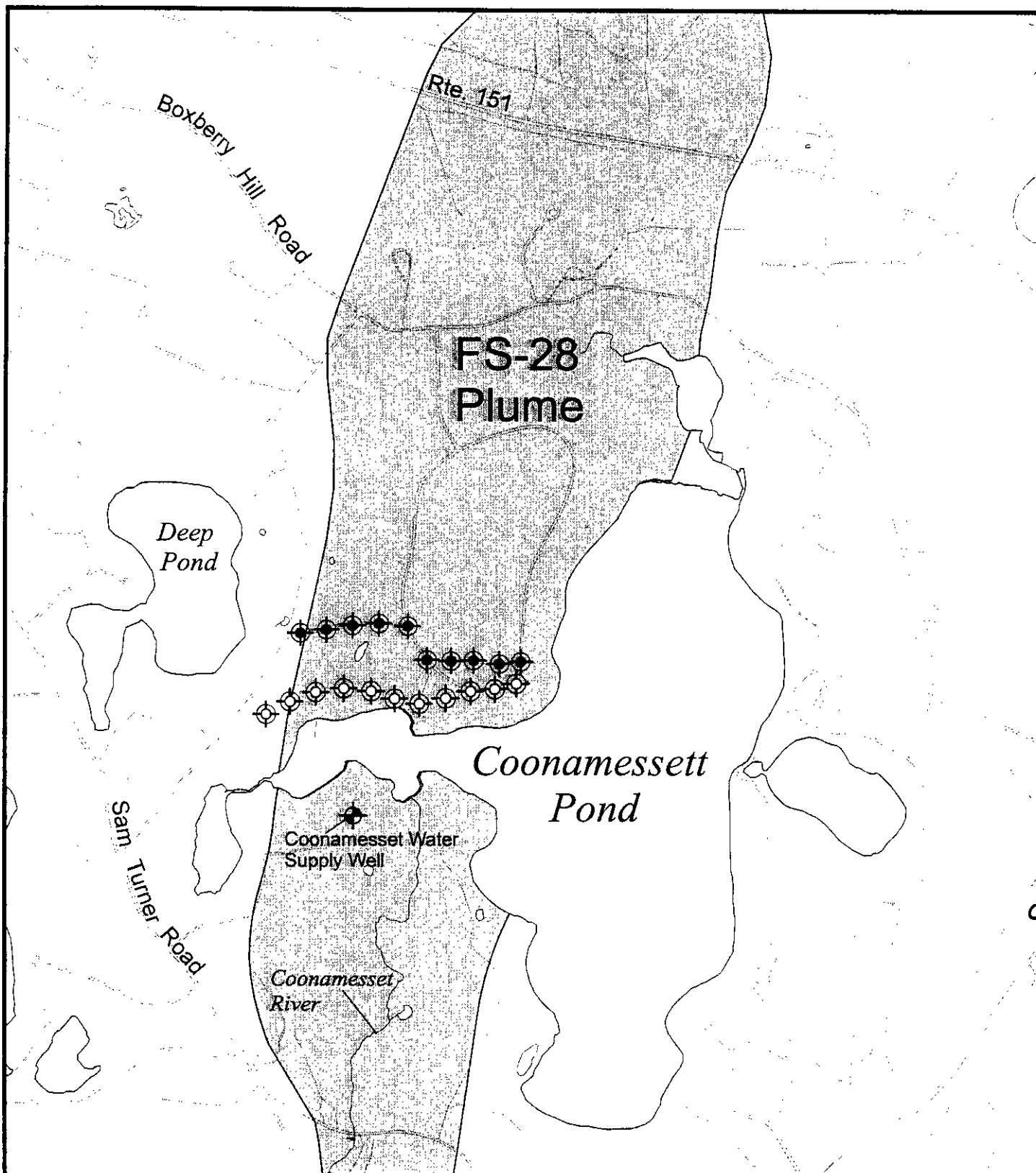
**JE** JACOBS ENGINEERING

#### FS-28 Plume Alternative 4 Conceptual Well Layout

Massachusetts Military Reservation  
Cape Cod, Massachusetts

6/21/99 jlb FS28-GF-1.cdr

Figure 5-3



#### Legend

- Plume Boundary
- Pond
- +
 Extraction Well
- +
 Reinjection Well

Alternative modeled at 400 gallons per minute

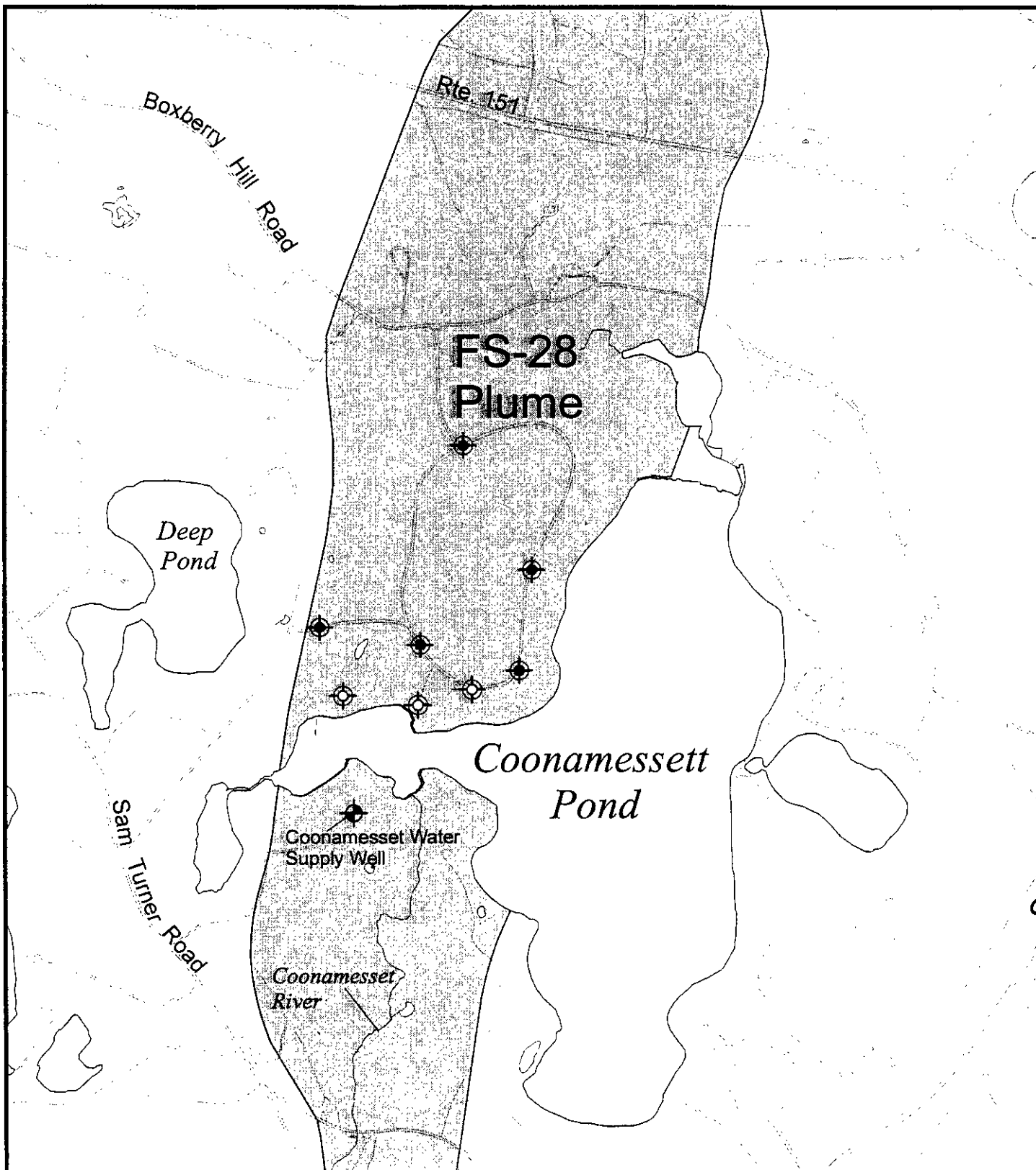
**JE** JACOBS ENGINEERING

#### FS-28 Plume Alternative 5 Conceptual Well Layout





Massachusetts Military Reservation  
Cape Cod, Massachusetts

6/21/99 jb FS28-GF-1.cdr

Figure 5-4



### Legend

- |   |                |   |                  |
|---|----------------|---|------------------|
|  | Plume Boundary |  | Extraction Well  |
|  | Pond           |  | Reinjection Well |

Alternative modeled at 600 gallons per minute

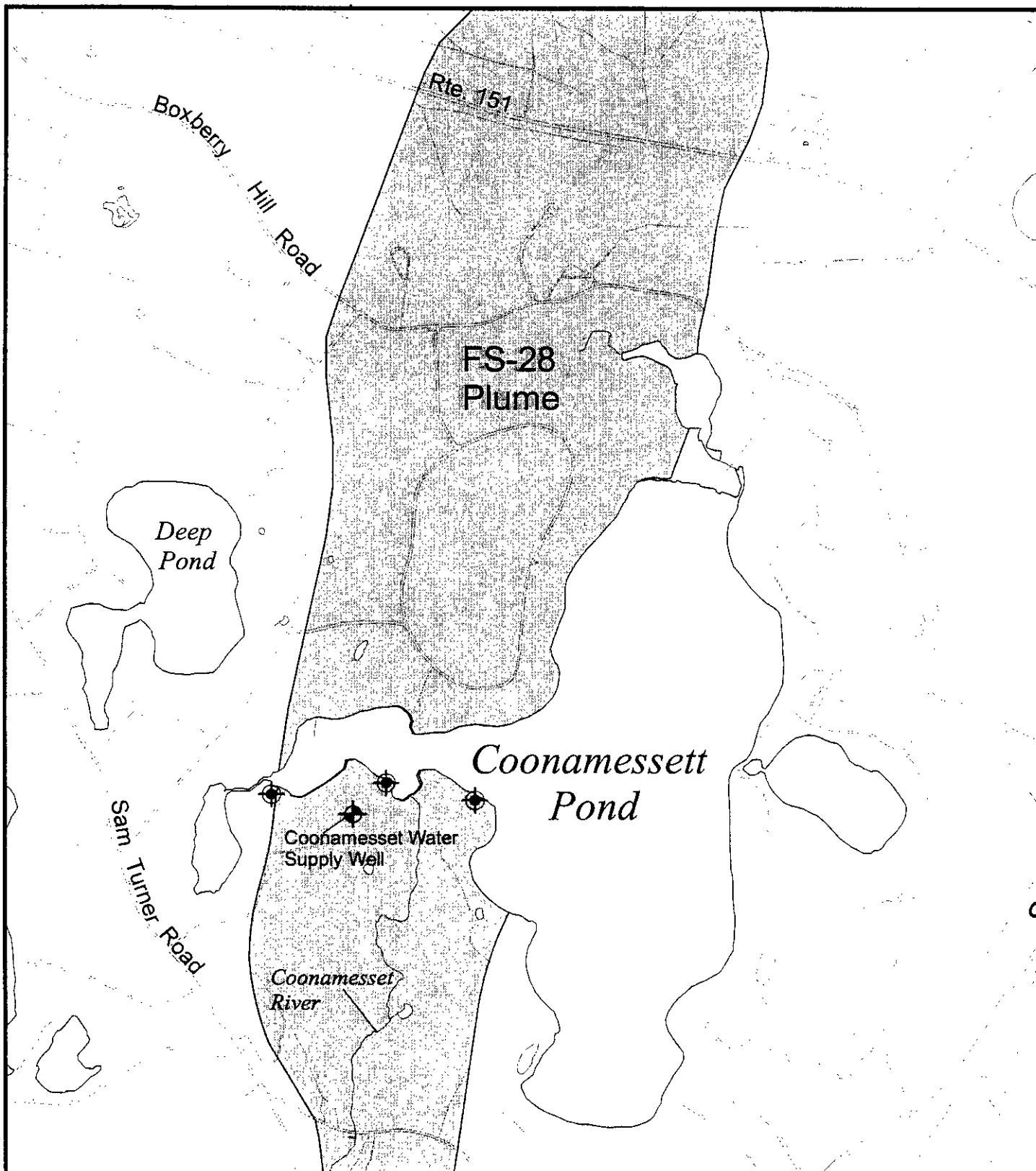
**JE** JACOBS ENGINEERING

### FS-28 Plume Alternative 6 Conceptual Well Layout

Massachusetts Military Reservation  
Cape Cod, Massachusetts

6/21/99 jb FS28-GF-1.cdr

Figure 5-5



#### Legend

- Plume Boundary
- Pond
- +

 Proposed Extraction Well

**JE** JACOBS ENGINEERING

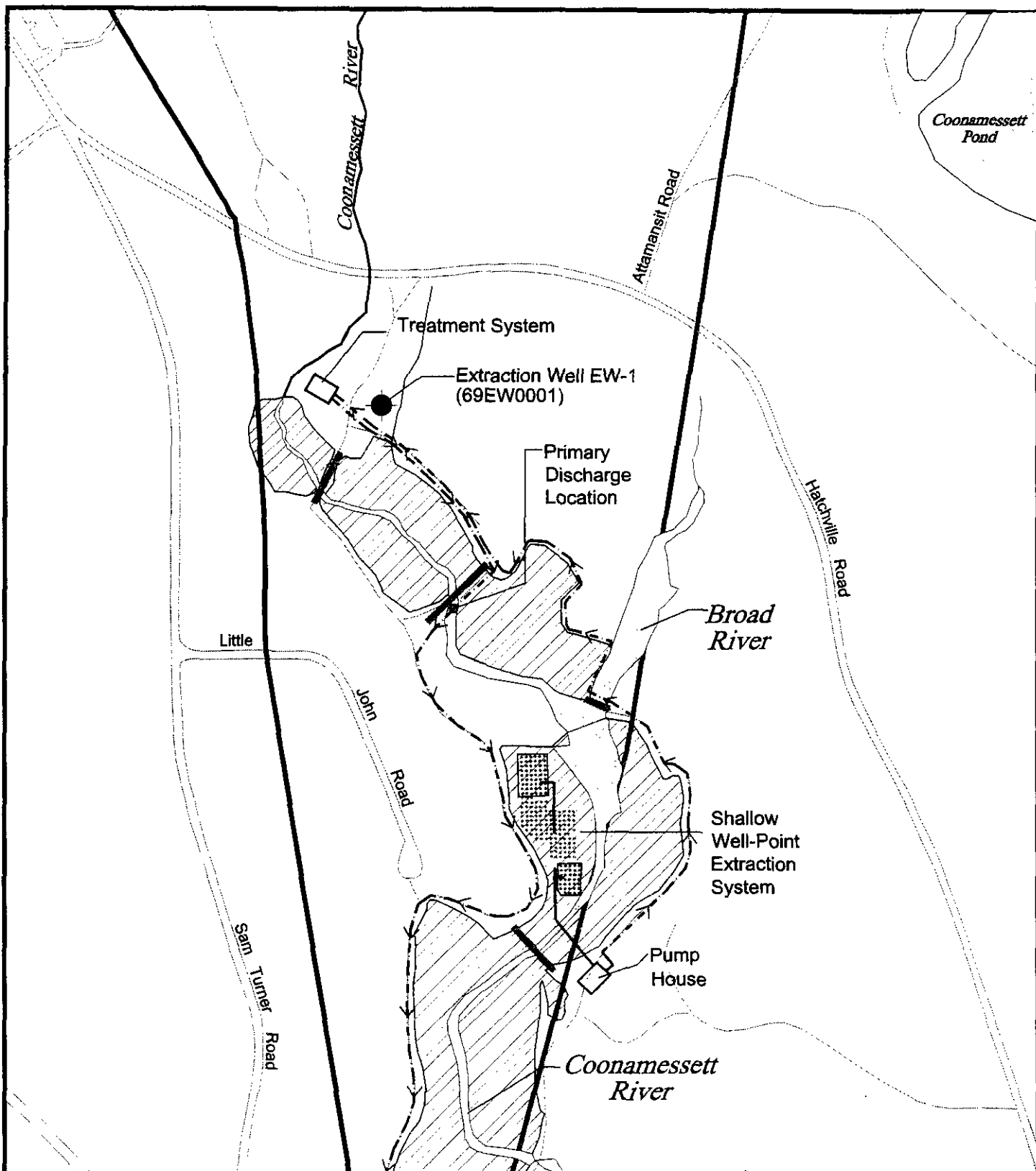
#### FS-28 Plume Alternative 7 Conceptual Well Layout

Massachusetts Military Reservation  
Cape Cod, Massachusetts







Alternative modeled at 600 gallons per minute

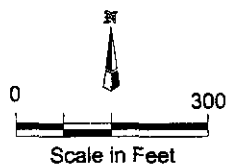
6/21/99 jb FS28-GF-1.cdr

Figure 5-6



### Legend

- |   |   |   |          |
|---|---|---|----------|
|  | Well-Points Not Pumping                 |  | Bogs     |
|  | Well-Points Pumping                     |  | Pipeline |
|  | Berm                                    |   |          |
|  | FS-28 Plume Contour<br>(EDB = 0.02µg/L) |   |          |



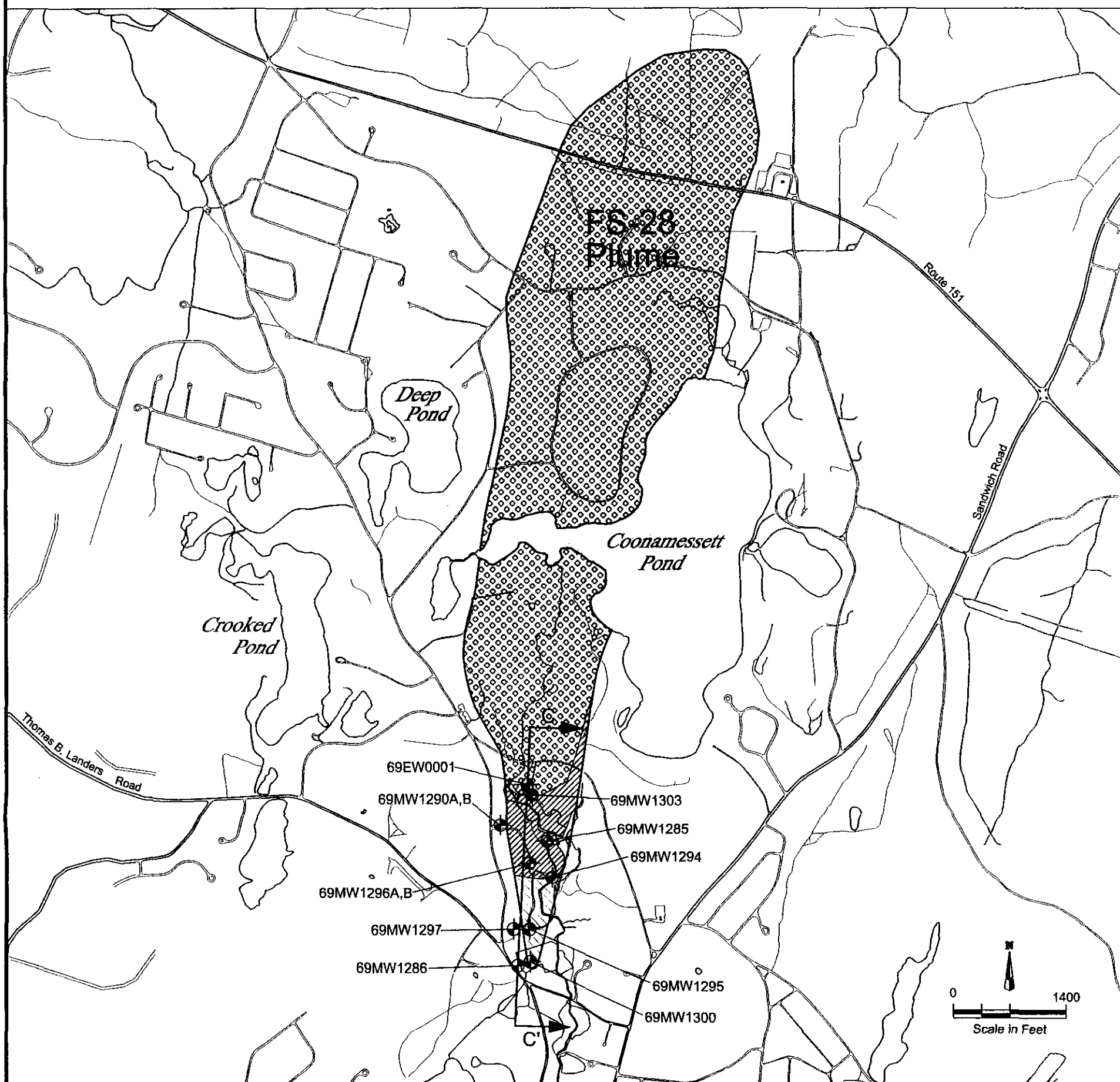
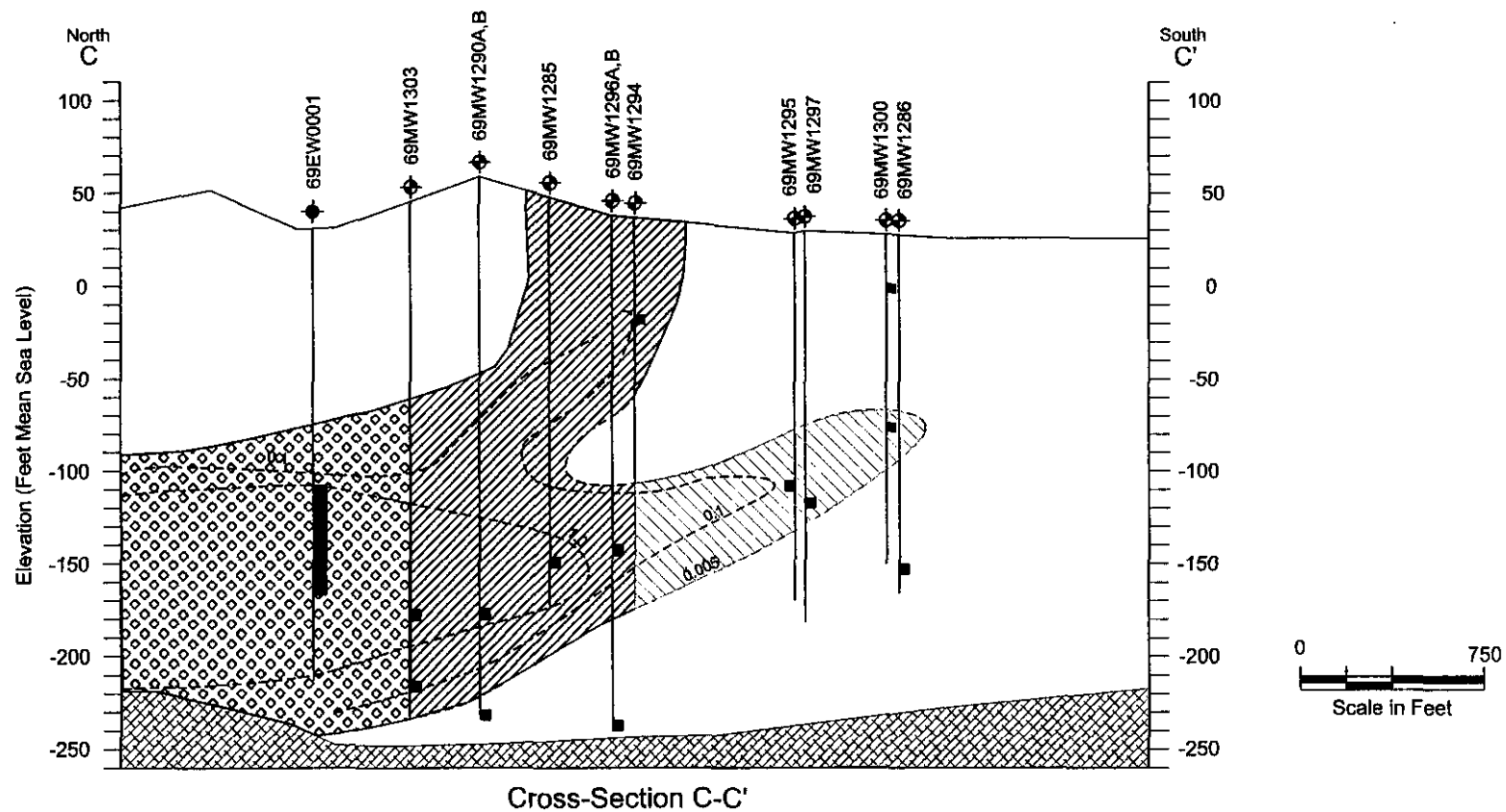
JACOBS ENGINEERING

### Key Treatment Components of Alternative 3 for the FS-28 Plume

Massachusetts Military Reservation  
Cape Cod, Massachusetts

1/3/00 mm File...FS28-29FS-5.dwg

Figure 5-7



#### Legend

▼ Water Table

Approximate extent of FS-28 Plume captured by EW-1.

Approximate extent of uncaptured portion of FS-28 Plume.

Monitoring Well

Approximate extent of FS-28 Plume captured by proposed shallow well extraction system.

Bedrock

**JE** JACOBS ENGINEERING

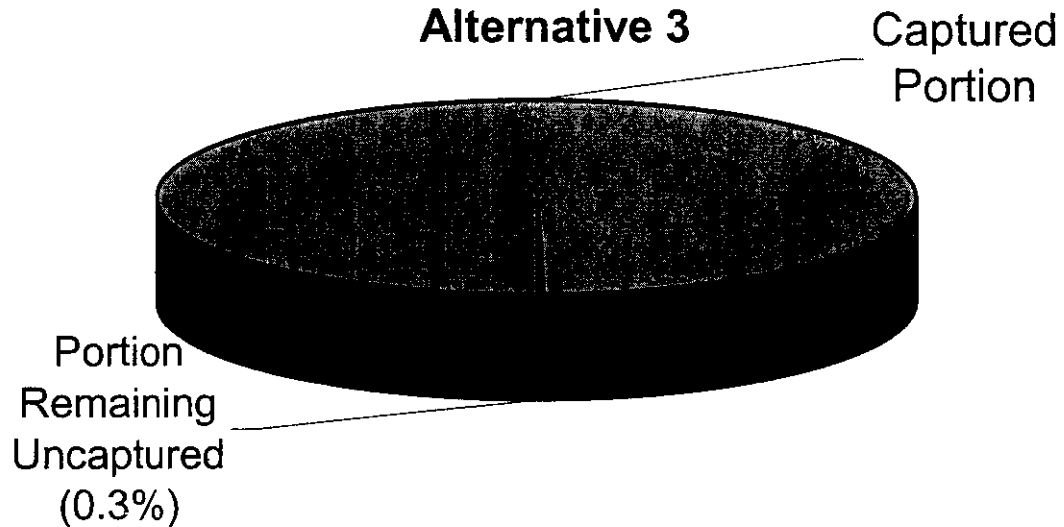
#### FS-28 Plume Capture Under Alternative 3

Massachusetts Military Reservation  
Cape Cod, Massachusetts

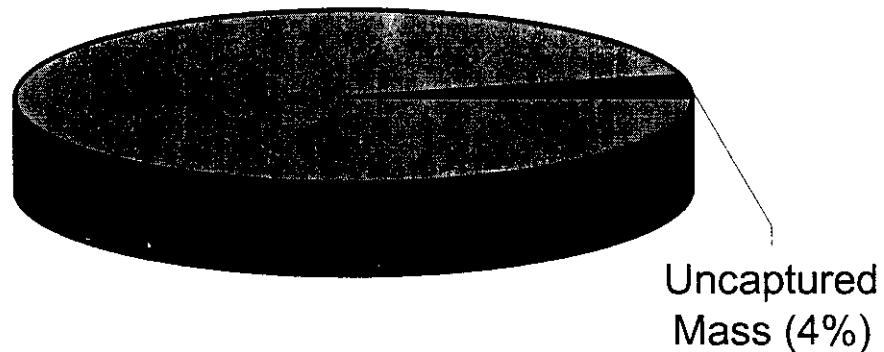
10/28/99 sr File...FS28-29FS-6.dwg

Figure 5-8

### Portion of FS-28 Plume Uncaptured by Alternative 3



### Uncaptured Portion Compared to EDB Mass Captured by EW-1 During Its First Year of Operation



**JE**

**JACOBS ENGINEERING**

**Comparisons of Mass that Will Remain  
Uncaptured Under Alternative 3**

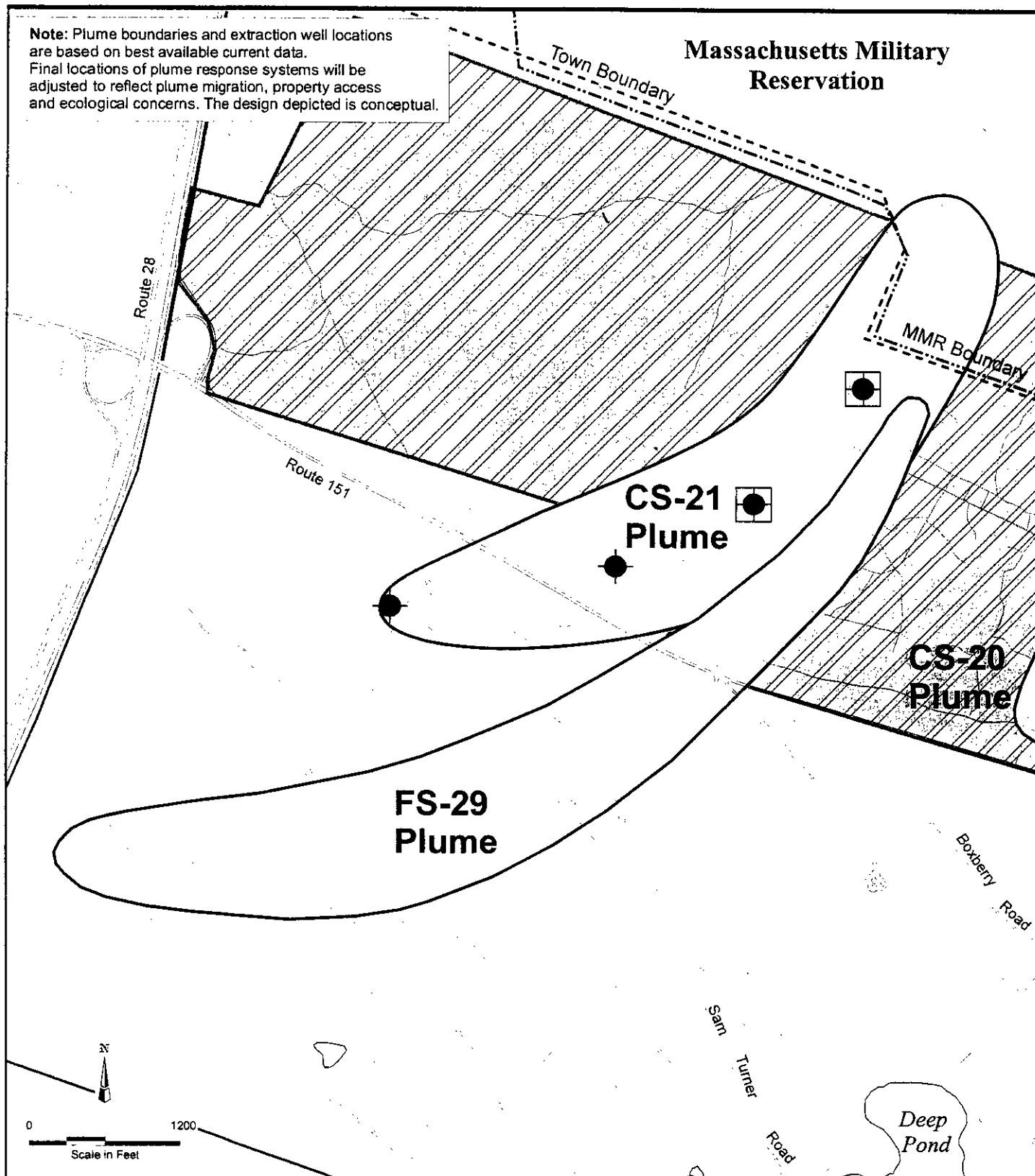
Massachusetts Military Reservation

Cape Cod, Massachusetts

I:\35q86101\Final FS28\Pie.xls

**Figure 5-9**

**Note:** Plume boundaries and extraction well locations are based on best available current data. Final locations of plume response systems will be adjusted to reflect plume migration, property access and ecological concerns. The design depicted is conceptual.



#### Legend

- Plume Contour (TCE, PCE MCL = 5.0 µg/L)
- MMR Boundary
- Town Boundary
- Extraction Well



Crane Wildlife Management Area



Ponds



Paired Deep and Shallow Extraction Well



JACOBS ENGINEERING

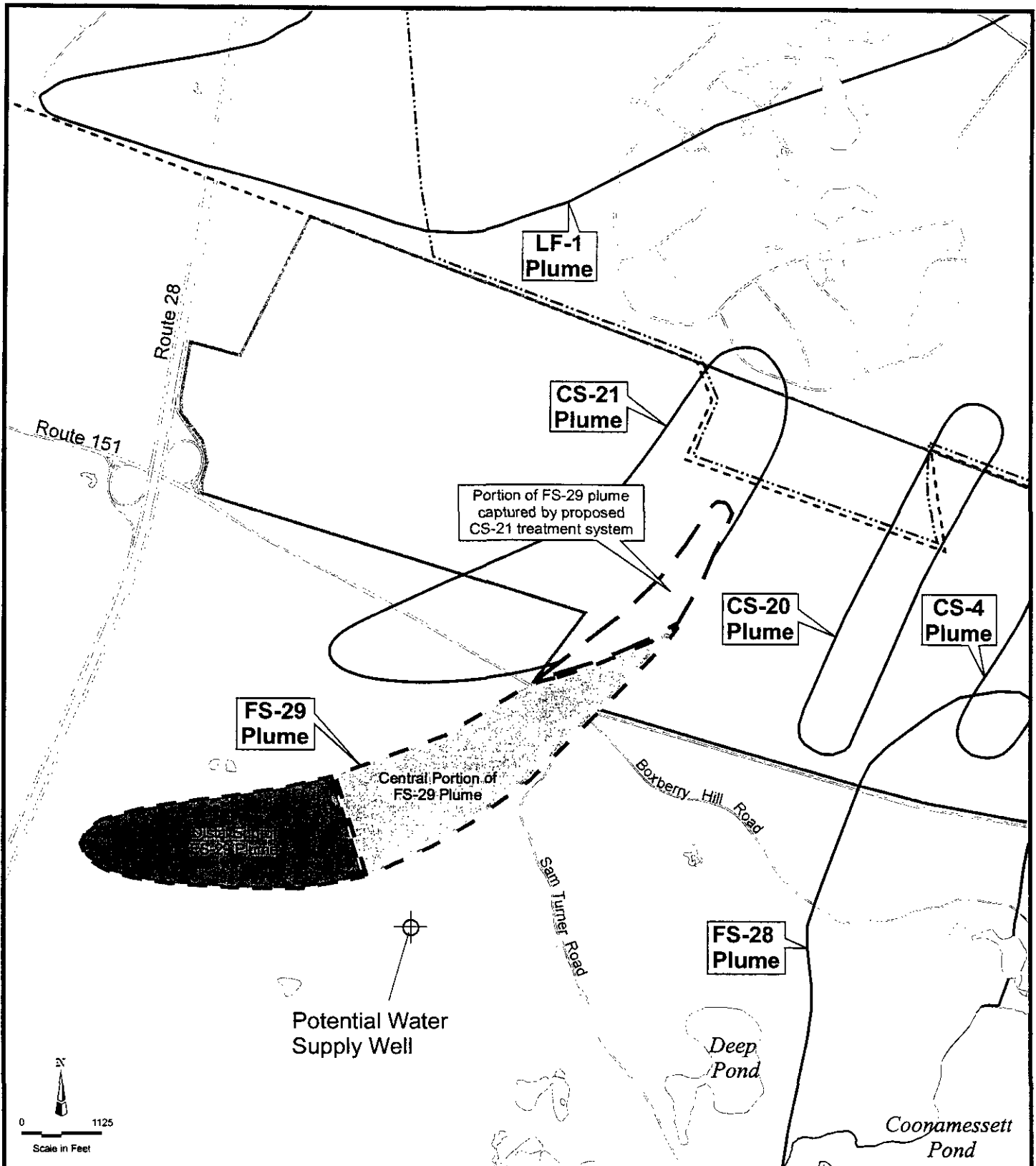
Conceptual Design for  
the Selected Remedy  
for the CS-21 Plume

Massachusetts Military Reservation  
Cape Cod, Massachusetts

10/28/99 sr FS28-29FS-2.cdr

Figure 6-1





#### Legend

- Plume Contour  
(TCE, PCE MCL = 5.0 µg/L)
- MMR Boundary
- Town Boundary
- Potential Water Supply Well



- Crane Wildlife Management Area
- Portion of FS-29 plume captured by proposed CS-21 treatment system
- Central portion of FS-29 plume
- Distal end of FS-29 plume



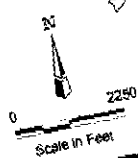
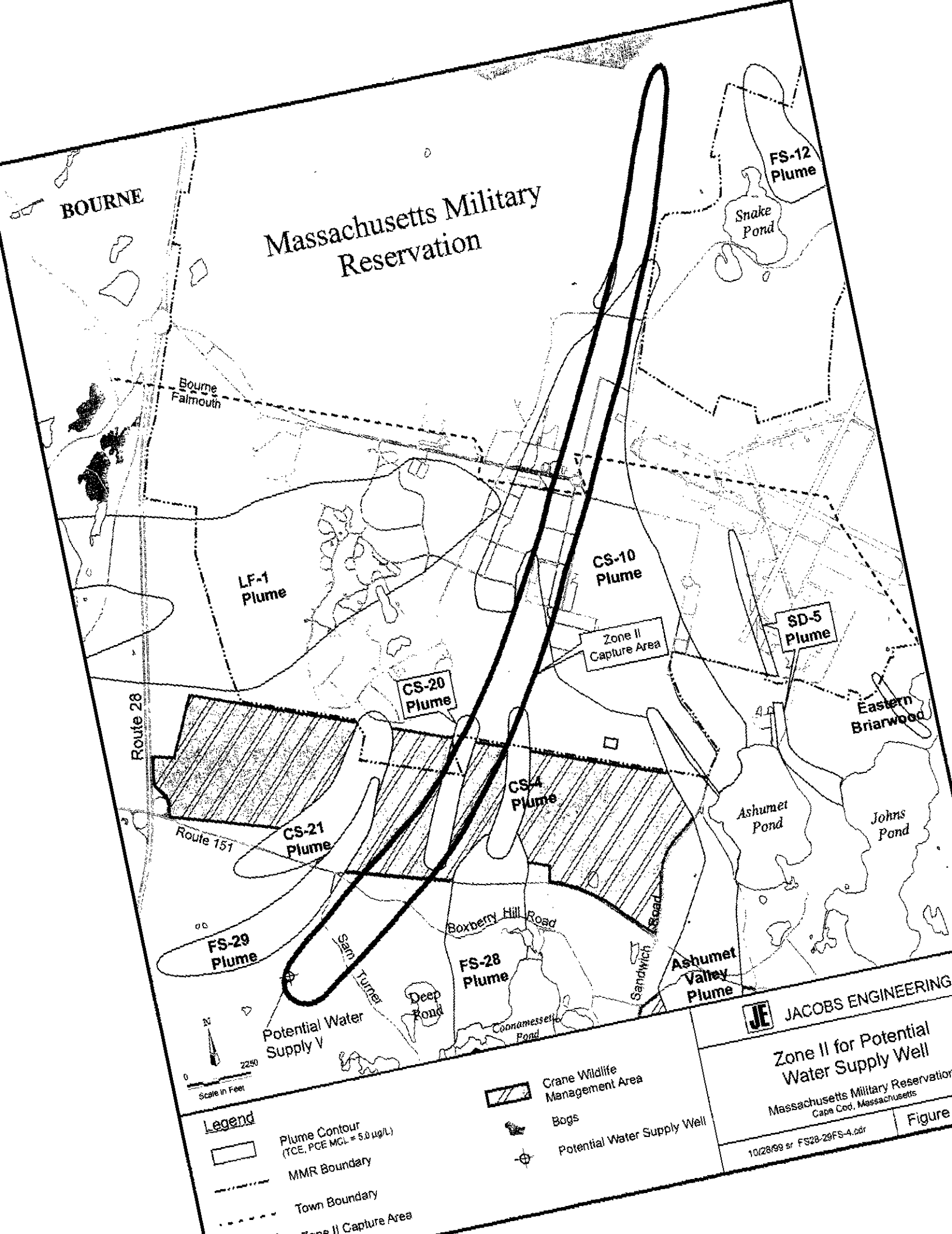
JACOBS ENGINEERING

#### Division of FS-29 Plume

Massachusetts Military Reservation  
Cape Cod, Massachusetts

10/28/99 sr FS28-29FS-3.cdr

Figure 6-2



**Legend**

- Plume Contour (TCE, PCE MCL = 5.0 µg/L)
- MMR Boundary
- Town Boundary
- Zone II Capture Area

- Crane Wildlife Management Area
- Bogs
- Potential Water Supply Well



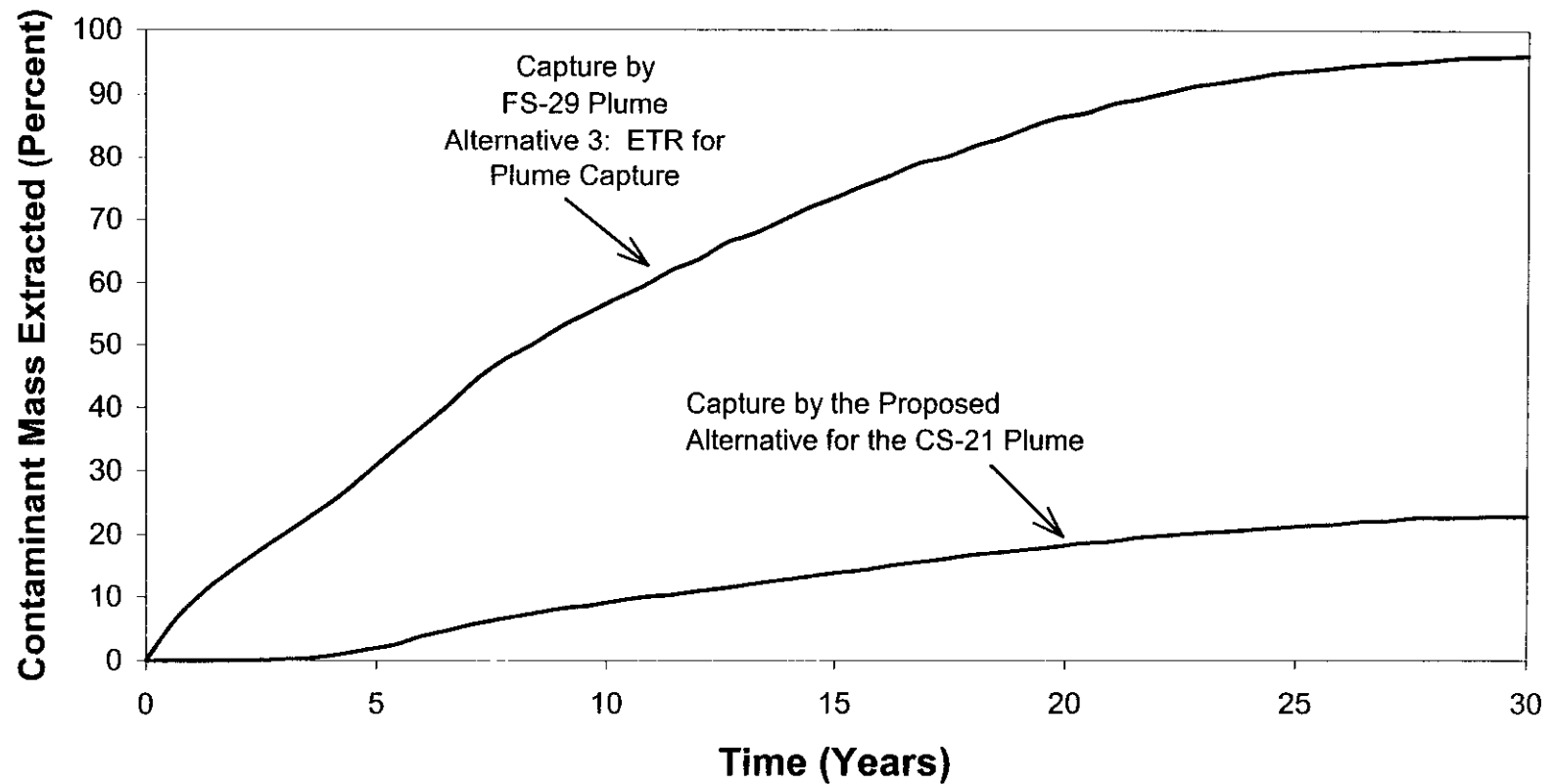
JACOBS ENGINEERING

**Zone II for Potential Water Supply Well**

Massachusetts Military Reservation  
Cape Cod, Massachusetts

10/28/99 sr FS28-28FS-4.cdr

Figure



**JE JACOBS ENGINEERING**

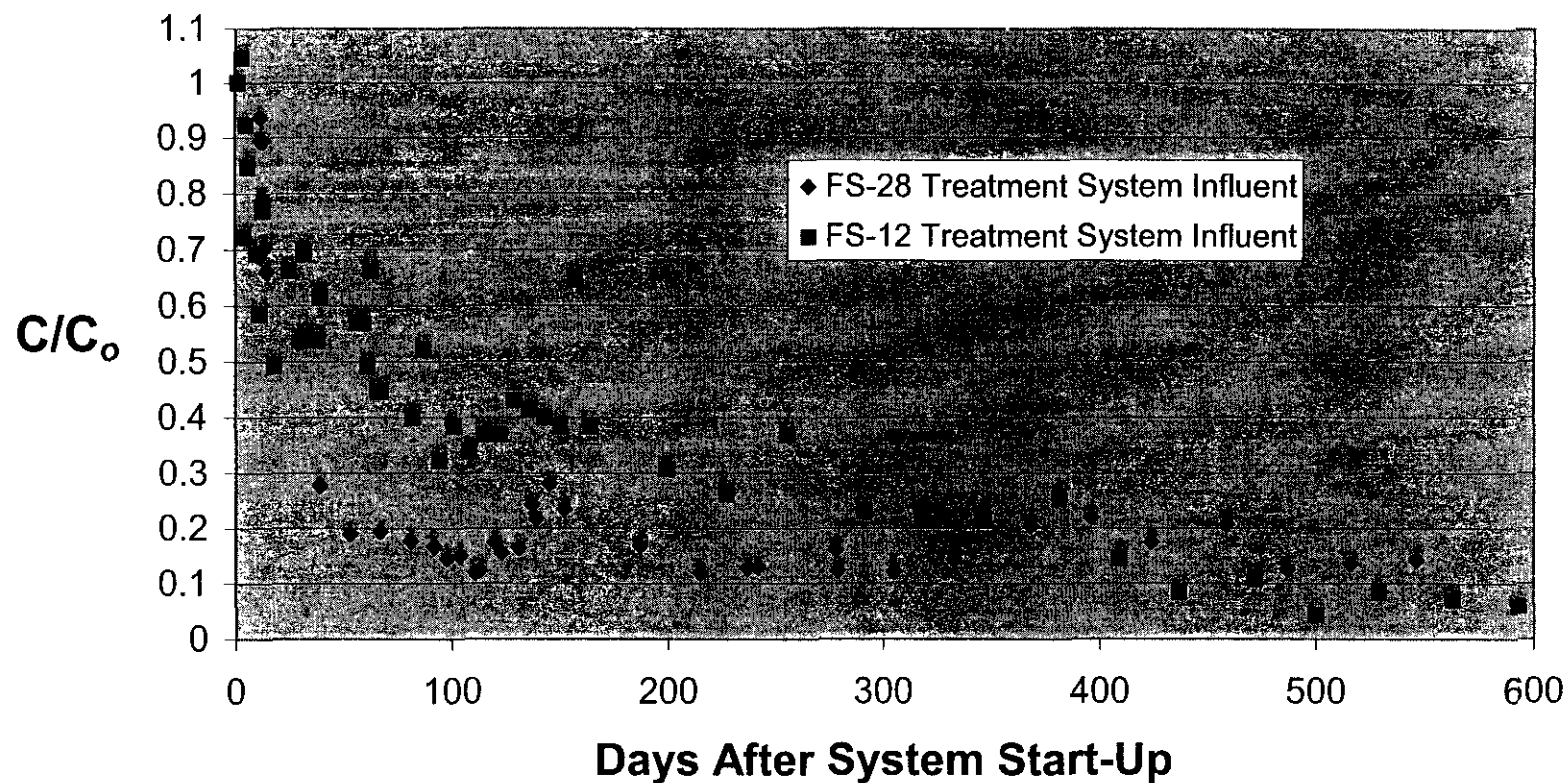
**Portion of FS-29 Plume Captured by Active Remedial Alternatives**

Massachusetts Military Reservation  
Cape Cod, Massachusetts

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Figure 6-4

## Treatment System Influent EDB Concentrations



**Notes:**

$C/C_0$  = influent EDB concentrations divided by start-up influent EDB concentration [unitless]

Results from the FS-28 treatment system collected after start-up of the well-point extraction system are not included.

EDB = ethylene dibromide

JE JACOBS ENGINEERING

**FS-12 and FS-28 Treatment Systems  
Influent EDB Concentrations**

Massachusetts Military Reservation

Cape Cod, Massachusetts

I:\35q86101\Final FS28\FS12 TP.xls

Figure 6-5

**APPENDIX A**

**Applicable or  
Relevant and Appropriate Requirements  
(ARARS)**

## APPENDIX A TABLE OF CONTENTS

ACRONYMS AND ABBREVIATIONS .....	A-iii
----------------------------------	-------

### **Tables**

Table 1	FS-28 Plume Chemical-Specific ARARs
Table 2	FS-28 Plume Location-Specific ARARs
Table 3	FS-28 Plume Action-Specific ARARs
Table 4	FS-29 Plume Chemical-Specific ARARs
Table 5	FS-29 Plume Location-Specific ARARs
Table 6	FS-29 Plume Action-Specific ARARs

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## ACRONYMS AND ABBREVIATIONS

Alt.	alternative
ARARs	applicable or relevant and appropriate requirements
CFR	Code of Federal Regulations
CMR	Code of Massachusetts Regulations
CWA	Clean Water Act
COC	contaminant of concern
CWSW	Coonamesett Water Supply Well
DEP	Massachusetts Department of Environmental Protection
EDB	ethylene dibromide (1,2-dibromoethane)
EPA	U.S. Environmental Protection Agency
ETD	extraction, treatment and discharge
ETR	extraction, treatment and reinjection
FS-28	Fuel Spill 28
HWMR	Hazardous Waste Material Requirements
MA	Massachusetts
MCL	maximum contaminant level
MMCL	Massachusetts maximum contaminant level
MMR	Massachusetts Military Reservation
N/A	requirement is not applicable to listed alternative
NPDES	National Pollutant Discharge Elimination System
ppm	parts per million
RCRA	Resource Conservation and Recovery Act
SDWA	Safe Drinking Water Act
TCLP	Toxicity Characteristic Leaching Procedure



TSD	transportation, storage, and disposal
USC	United States Code
VOC	volatile organic compound

**APPENDIX A Table 1  
FS-28 Plume Chemical-Specific ARARs**

Requirement	Status	Requirement Synopsis	Action to be Taken to Attain Requirement
<b>Federal Regulations and Guidance</b>			
SDWA - MCLs (40 CFR 141.61-141.63)	Relevant and Appropriate	The purpose of the SDWA is to protect United States drinking water resources. MCLs have been promulgated for organic and inorganic contaminants. These levels regulate the concentration of contaminants in public drinking water supplies, but may also be considered relevant and appropriate for groundwater aquifers used for drinking water.	Alt. 1: No action would be taken under this alternative. Alt. 3, 6, & 7: MCLs will be used as cleanup goals and met for all contaminants of concern throughout the plume.
<b>State Regulations</b>			
Massachusetts Drinking Water Standards (310 CMR 22.00)	Relevant and Appropriate	Massachusetts Drinking Water Standards establish MMCLs for public drinking water systems. When state MCLs are more stringent than federal levels, the state levels must be attained. The state MCL for EDB is 0.02 micrograms per liter, which is more stringent than the federal MCL of 0.05 micrograms per liter.	Alt. 1: No action would be taken under this alternative. Because the Coonamessett Water Supply Well wellhead treatment system would discontinue operations, the alternative fails to ensure that area residents will not be exposed to drinking water with contaminant concentrations in excess of MMCLs. In the aquifer, the MMCLs for all COCs will be attained in approximately 18 years.

**APPENDIX A Table 1**  
**FS-28 Plume Chemical-Specific ARARs**

Requirement	Status	Requirement Synopsis	Action to be Taken to Attain Requirement
Massachusetts Drinking Water Standards (310 CMR 22.00) (cont.)			Alt. 3, 6, & 7: Area residents have previously been connected to public drinking water supplies. The CWSW wellhead treatment system will help ensure that public water supplies will not be exposed to plume contaminants. For the ETD (and ETR for Alt. 6) system(s), MMCLs are relevant and appropriate. The ETD (and ETR) system(s) will be designed to treat extracted groundwater to MMCLs. MMCLs, where more stringent than MCLs, will be used as cleanup goals and will be met for all contaminants of concern throughout the plume. Under Alt. 3 MMCLs will be attained in approximately 18 years; under Alt. 6 in approximately 11 years; and under Alt. 7 in approximately 9 years. <b>Note:</b> Actions proposed under Alt. 3 remove EDB before discharge but require natural, advective flow to move contaminants to the extraction point. Therefore, this alternative does not significantly reduce the time COC concentrations exceeding MMCLs will remain in the aquifer.
Massachusetts Groundwater Quality Standards (314 CMR 6.00)	Applicable	These standards limit the concentration of certain materials allowed in classified Massachusetts waters. The groundwater beneath MMR has been classified as a Class I water (fresh groundwater found in the saturated zone of unconsolidated deposits) and is designated as a source of potable water supply.	Alt. 1, 3, & 7 : N/A. (Alt. 3 & 7 only involve discharge to surface water.) Alt. 6: The ETR system in the body of the plume will be designed and operated to treat groundwater to obtain groundwater quality standards prior to reinjection.

**APPENDIX A Table 1  
FS-28 Plume Chemical-Specific ARARs**

<b>Requirement</b>	<b>Status</b>	<b>Requirement Synopsis</b>	<b>Action to be Taken to Attain Requirement</b>
Massachusetts Surface Water Quality Standards (314 CMR 4.00)	Relevant and Appropriate	These regulations limit or prohibit discharges of pollutants to surface waters to assure that surface water quality standards of the receiving waters are protected and maintained or attained. Discharges may be limited or prohibited to protect existing uses and not interfere with the attainment of designated uses in downstream and adjacent segments.	Alt. 1: N/A Alt. 3, 6, & 7: Discharge of treated water into the Coonamessett River will comply with these requirements for a Class B river.

Alt 1: No Remedial Action with Long-Term Monitoring

Alt 3: Continued Treatment System Operations

Alt 6: Continued Remedial Operations with Capture North of the Western Arm of Coonamessett Pond

Alt 7: Continued Remedial Operations with Additional Extraction and Treatment in the Souza Conservation Area

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**APPENDIX A Table 2  
FS-28 Plume Location-Specific ARARs**

Requirement	Status	Requirement Synopsis	Action to be Taken to Attain Requirement
<b>Federal Regulations and Guidance</b>			
Rivers and Harbors Act of 1899 (33 USC 403; 33 CFR Parts 320-323)	Applicable	Section 10 of the Rivers and Harbors Act of 1899 requires authorization from the Secretary of the Army, acting through the Army Corps of Engineers, for the construction of any structure in or over any "navigable water of the U.S." It also requires such authorization for the excavation from or deposition of material in such waters, or any obstruction or alteration in such waters.	Alt. 1: N/A Alt. 3, 6, & 7: All actions within navigable waters will be coordinated with the Army Corps of Engineers.
Protection of Wetlands - Executive Order 11990 (40 CFR 6, Appendix A)	Applicable	Appendix A of 40 CFR 6 sets forth policy for carrying out provisions of the Protection of Wetlands Executive Order. Under this order, federal agencies are required to minimize the degradation, loss, or destruction of wetlands, and to preserve the natural and beneficial values of wetlands. Appendix A requires that no remedial alternatives adversely affect a wetland if another practicable alternative is available. If no alternative is available, effects from implementing the chosen alternative must be mitigated.	Alt. 1: N/A Alt. 3, 6, & 7: Remedial actions within a cranberry bog or other wetland will be done in a manner to minimize the impact. Altered areas will be repaired or restored.
Fish and Wildlife Coordination Act (16 USC 661 et seq., 40 CFR 6.302)	Applicable	This act requires that any federal agency proposing to modify a body of water must consult with the U.S. Fish and Wildlife Service, National Marine Fisheries Services, and related state agencies to develop measures to prevent, mitigate or compensate for project-related losses to fish and wildlife. Such action should be viewed in the context of obtaining maximum overall project benefits such as cleaning up the site. The requirements to comply with this Act are contained in EPA's NPDES permit regulations (40 CFR 122.49).	Alt. 1: N/A Alt. 3, 6, & 7: Actions will be taken to develop measures to prevent, mitigate or compensate for project-related impacts to fish and wildlife. Relevant agencies will be contacted to help analyze the impact on fish and wildlife from installing treatment systems, and discharging treated water to the Coonamessett River.
CWA Section 404, 40 CFR Part 230, 33 CFR Parts 320-323	Applicable	No activity that adversely affects a wetland shall be permitted if a practicable alternative with less effects is available. If no practicable alternative exists, impacts must be mitigated.	Alt. 1: N/A Alt. 3, 6, & 7: Design, installation and operation of the treatment system is being undertaken to minimize impacts to wetlands. All impacts will be mitigated.

**APPENDIX A Table 2**  
**FS-28 Plume Location-Specific ARARs**

<b>Requirement</b>	<b>Status</b>	<b>Requirement Synopsis</b>	<b>Action to be Taken to Attain Requirement</b>
Floodplain Management, Executive Order 11988 (40 CFR Part 6, Appendix A)	Applicable	Requires federal agencies to minimize potential harm to or within floodplains and avoid floodplain development wherever there is a practicable alternative.	Alt. 1: N/A Alt. 3, 6, & 7: Proposed activities do not harm the floodplain. Treatment facilities are/would be located outside the 100-year floodplain.
<b>State Regulations</b>			
Massachusetts Wetlands Regulations (310 CMR 10.00)	Applicable	These regulations protect inland and coastal wetlands, as well as a 100-foot buffer zone, from activities that may alter the resource area. Some wetlands receive additional protection as wildlife habitat. Status of wildlife habitat is determined by the presence of particular plant communities or hydrologic characteristics. The regulations specifically prohibit the loss of over 5,000 square feet of bordering vegetated wetlands. The loss may be permitted with replication of the lost area within two growing seasons.	Alt. 1: N/A Alt. 3, 6, & 7: All activities within wetland areas and buffer zones will be conducted to meet all requirements. If FS-28 remedial actions alter more than 5,000 square feet of protected area, the affected area will be restored within two growing seasons.
Massachusetts Endangered Species Act (321 CMR 8.00)	Applicable	The Commonwealth of Massachusetts has authority to research, list, and protect any species deemed endangered, threatened, or of other special concern. These species are listed as either endangered, threatened, or species of special concern in the regulations. The Massachusetts lists may differ from the federal lists of endangered species. Actions must be conducted in a manner that minimizes the effect on Massachusetts-listed endangered species and species listed by the Massachusetts Natural Heritage Program.	Alt. 1: N/A Alt. 3, 6, & 7: Several state-listed species have been identified in the vicinity of MMR. Areas in which work is to be conducted are being evaluated for the presence of habitat for endangered or threatened species. Activities will be designed to meet the requirements of these regulations.

Alt 1: No Remedial Action with Long-Term Monitoring

Alt 3: Continued Treatment System Operations

Alt 6: Continued Remedial Operations with Capture North of the Western Arm of Coonamessett Pond

Alt 7: Continued Remedial Operations with Additional Extraction and Treatment in the Souza Conservation Area

**APPENDIX A Table 3  
FS-28 Plume Action-Specific ARARs**

Requirement	Status	Requirement Synopsis	Action to be Taken to Attain Requirement
<b>Federal Regulations and Guidance</b>			
National Pollutant Discharge Elimination System (NPDES) (40 CFR 122-125 and 131)	Applicable	Establishes discharge limitations, monitoring requirements and best management practices for any direct discharge from a point source into surface water.	Alt. 1: N/A Alt. 3, 6, & 7: Discharges of treated water from the ETD system into the Coonamessett River or cranberry bogs will meet these standards.
RCRA - Identification and Listing of Hazardous Wastes; Toxicity Characteristics (40 CFR Part 261.24)	Relevant and Appropriate	These requirements identify the maximum concentrations of contaminants for which the waste would be a RCRA-characteristic hazardous waste for toxicity. The analytical test given in Appendix II is referred to as the TCLP.	Alt. 1 : N/A Alt. 3, 6, & 7: Drill cuttings, spent activated carbon, and sludge sent offsite for disposal (not including regeneration) will be analyzed according to the TCLP. If TCLP results exceed the standards in 261.24, the material will be disposed of offsite in a RCRA-permitted treatment storage and disposal facility.
Underground Injection Control Program, 40 CFR 144, 146, 147, 1000.	Applicable	These regulations outline minimum program and performance standards for underground injection wells and prohibit any injection that may cause a violation of any primary drinking water regulation in the aquifer.	Alt. 1, 3, & 7: N/A Alt. 6: Reinjection wells for in-plume ETR system will be designed to meet these standards.
RCRA Subtitle C, 40 CFR Part 264 - Standards for Owners and Operators of Hazardous Waste Treatment, Storage and Disposal Facilities.	Relevant and Appropriate	These standards, which regulate the operation of facilities that treat, store, or dispose of hazardous waste, take effect through authorized state RCRA programs cited below (Massachusetts HWMR and Hazardous Waste Management Regulations).	Alt. 1: N/A Alt. 3, 6, & 7: See MA hazardous waste regulations cited below.



**APPENDIX A Table 3  
FS-28 Plume Action-Specific ARARs**

<b>Requirement</b>	<b>Status</b>	<b>Requirement Synopsis</b>	<b>Action to be Taken to Attain Requirement</b>
RCRA Air Emission Standards for Process Vents (40 CFR 264, Subpart AA)	Relevant and Appropriate	These regulations establish requirements for controlling emissions from process vents associated with treatment processes that manage hazardous wastes with organic concentrations of 10 ppm or more.	Alt. 1: N/A Alt. 3, 6, & 7: If thresholds are met, emissions from process vents will be controlled in accordance with these requirements.
Standards for Control of Emissions of VOCs, RCRA (40 CFR 264, Subpart BB)	Relevant and Appropriate	Contains air pollutant emissions standards for equipment leaks at hazardous waste TSD facilities. Contains design specifications and requirements for monitoring for leak detection. It is applicable to equipment that contains hazardous wastes with organic concentrations of at least 10% by weight.	Alt. 1: N/A Alt. 3, 6, & 7: If treatment involves groundwater with organic concentrations of at least 10% by weight, equipment will meet design specifications and will be monitored for leaks.
<b>State Regulations</b>			
Massachusetts Department of Public Health Food Tolerance Action Levels (105 CMR 515.00)	To Be Considered	Establishes food tolerance action levels for EDB.	Alt. 1: No action will be taken. Alt. 3, 6, & 7: The FS-28 treatment system and well point extraction system will minimize the possibility that concentrations of EDB exceeding the food tolerance action levels are present in the cranberry crop. Cranberries will be sampled and analyzed as an additional measure of the performance of the alternative.

**APPENDIX A Table 3  
FS-28 Plume Action-Specific ARARs**

Requirement	Status	Requirement Synopsis	Action to be Taken to Attain Requirement
Massachusetts Air Pollution Control Regulations (310 CMR 7.00)	Applicable	These regulations set emission limits necessary to attain ambient air quality standards.	Alt. 1: N/A Alt. 3: Operation of the treatment systems will be conducted to meet standards for volatile organic compounds (310 CMR 7.18). Alt. 6 & 7: Remedial actions (e.g., well drilling and the installation of piping) will be conducted to meet the standards for visible emissions (310 CMR 7.06); dust, odor, construction, and demolition (310 CMR 7.09); noise (310 CMR 7.10); and volatile organic compounds (310 CMR 7.18). If standards are exceeded, emissions will be managed through engineering controls.
Massachusetts HWMR - Requirements for Generators (310 CMR 30.300-30.371)	Relevant and Appropriate	This requirement sets standards for generators of hazardous waste that address (1) accumulating waste, (2) preparing hazardous waste for shipment, and (3) preparing the uniform hazardous waste manifest. Massachusetts specifies requirements for very small quantity generators, as well as small and large quantity generators.	Alt. 1: N/A Alt. 3, 6, & 7: If RCRA-characteristic hazardous wastes are generated, the material will be managed in accordance with these requirements.
Massachusetts Hazardous Waste Management Regulations - Location Standards for Facilities (310 CMR 30.700 - 30.707)	Relevant and Appropriate	Under these standards, a new facility may not be located in an area subject to flooding; within the watershed of a Class A or Class SA segment of the surface water body unless it is determined that there is no feasible alternative; on land overlying an actual, planned, or potential public or private drinking water source; or in the flow path of groundwater supplying water to an existing well. In addition, there shall be a minimum of 300 feet from the active portion of the facility to the facility property line.	Alt. 1 & 3: N/A Alt. 6 & 7: Any treatment facilities will be located and operated to fulfill these regulations unless there is no feasible alternative. A waiver may be requested for the distance from the treatment facility to the property line.

**APPENDIX A Table 3  
FS-28 Plume Action-Specific ARARs**

Requirement	Status	Requirement Synopsis	Action to be Taken to Attain Requirement
Massachusetts Underground Water Source Protection, 310 CMR 27.00	Applicable	Under these regulations, "no underground injection shall be allowed where a Class V well causes or allows movement of fluid containing any pollutant into underground sources of drinking water and the presence of such pollutant causes or is likely to cause a violation of any Massachusetts Drinking Water Regulation ... or ... adversely affects or is likely to adversely affect the health of persons." Class V wells are defined to include "recharge wells used to replenish the water in an aquifer."	Alt. 1, 3, & 7: N/A Alt. 6: Extracted groundwater will be treated to levels at or below federal and state drinking water standards to ensure that discharges to reinjection wells will not cause any violation of drinking water standards in the receiving aquifer.

Alt 1: No Remedial Action with Long-Term Monitoring

Alt 3: Continued Treatment System Operations

Alt 6: Continued Remedial Operations with Capture North of the Western Arm of Coonamessett Pond

Alt 7: Continued Remedial Operations with Additional Extraction and Treatment in the Souza Conservation Area

**APPENDIX A Table 4  
FS-29 Plume Chemical-Specific ARARs**

Requirement	Status	Requirement Synopsis	Action to be Taken to Attain Requirement
<b>Federal Regulations and Guidance</b>			
SDWA - MCLs (40 CFR 141.61-141.63)	Relevant and Appropriate	The purpose of the SDWA is to protect United States drinking water resources. MCLs have been promulgated for organic and inorganic contaminants. These levels regulate the concentration of contaminants in public drinking water supplies, but may also be considered relevant and appropriate for groundwater aquifers used for drinking water. The MCL (federal) for carbon tetrachloride is 5.0 micrograms per liter.	Alt. 1: No action will be taken to meet these standards. Existing connections to public drinking water supplies protect current area residents from residential exposure to groundwater with contaminant concentrations exceeding MCLs. In the aquifer, the MCL for carbon tetrachloride would be attained in approximately 10 years. Alt. 2: No action will be taken to meet these standards in the aquifer. This alternative will rely on existing connections to public water supplies for current residents and local well drilling restrictions to prevent exposures to contaminated groundwater by future residents. If necessary, a wellhead protection system will be designed and constructed to further protect area residents from residential exposure to groundwater with contaminant concentrations exceeding MCLs. In the aquifer, the MCL for carbon tetrachloride would be attained in approximately 10 years.

**APPENDIX A    Table 4**  
**FS-29 Plume Chemical-Specific ARARs**

Requirement	Status	Requirement Synopsis	Action to be Taken to Attain Requirement
SDWA - MCLs (Continued)			<p>Alt. 3: MCLs will be used as a cleanup goal and concentrations for all contaminants of concern will be reduced below MCLs throughout the plume. The treatment system will be designed to treat extracted water to concentrations less than MCLs prior to discharge into the aquifer. In the aquifer, this alternative will attain the MCL for carbon tetrachloride in approximately 5 years.</p> <p>Alt. 7: MCLs will be used as a cleanup goal and concentrations for all contaminants of concern will be reduced below MCLs throughout central and upgradient portions of the plume. The treatment system will be designed to treat extracted water to concentrations less than MCLs prior to discharge into the aquifer. In the aquifer, this alternative will attain the MCL for carbon tetrachloride in approximately 10 years.</p>

**APPENDIX A Table 4  
FS-29 Plume Chemical-Specific ARARs**

Requirement	Status	Requirement Synopsis	Action to be Taken to Attain Requirement
<b>State Regulations</b>			
Massachusetts Drinking Water Standards (310 CMR 22.00)	Relevant and Appropriate	Massachusetts Drinking Water Standards establish MMCLs for public drinking water systems. When state MCL levels are more stringent than federal levels, the state levels must be attained. The MMCL for EDB, which is 0.02 micrograms per liter, is more stringent than the federal MCL of 0.05 micrograms per liter.	<p>Alt. 1: No action will be taken under this alternative. Existing connections to public drinking water supplies protect current area residents from residential exposure to groundwater with contaminant concentrations exceeding MMCLs. In the aquifer, the MMCL for EDB would be attained in approximately 13 to 17 years from the (date of data acquisition).</p> <p>Alt. 2: No action will be taken to meet these standards in the aquifer. Existing connections to public drinking water supplies protect current area residents from residential exposure to groundwater with contaminant concentrations exceeding MMCLs. This alternative will rely on local well drilling restrictions to prevent exposures to contaminated groundwater by future residents. If necessary, a wellhead protection system will be designed and constructed to further protect the proposed water supply well. In the aquifer, the MMCL for EDB would be attained in approximately 13 to 17 years (from the date of data acquisition).</p> <p>Alt. 3: The MMCL for EDB will be used as a cleanup goal and will be met throughout the plume. All discharged water will comply with MMCLs. In the aquifer, the MMCL for EDB will be attained in approximately 8 years.</p> <p>Alt. 7: The MMCL for EDB will be used as a cleanup goal and will be met in the upgradient and central portions of the plume. All discharged water will comply with MMCLs. In the aquifer, the MMCL for EDB will be attained in approximately 10 years.</p>

**APPENDIX A Table 4  
FS-29 Plume Chemical-Specific ARARs**

Requirement	Status	Requirement Synopsis	Action to be Taken to Attain Requirement
Massachusetts Groundwater Quality Standards (314 CMR 6.00)	Relevant and Appropriate	These standards limit the concentration of certain materials allowed in classified Massachusetts waters. The groundwater beneath MMR has been classified as a Class I water (fresh groundwater found in the saturated zone of unconsolidated deposits) and is designated as a source of potable water supply.	Alt. 1 & 2: N/A Alt. 3 & 7: The system will be designed and operated to treat groundwater to obtain groundwater quality standards prior to discharge.

Alt. 1: No Remedial Action with Long-Term Monitoring.

Alt. 2: Institutional and Engineering Controls

Alt. 3: Extraction, Treatment and Reinjection for Plume Capture

Alt. 7: Extraction, Treatment and Reinjection to Capture the Central Portion of the FS-29 Plume

**APPENDIX A Table 5  
FS-29 Plume Location-Specific ARARs**

<b>Requirement</b>	<b>Status</b>	<b>Requirement Synopsis</b>	<b>Action to be Taken to Attain Requirement</b>
<b>State Regulations</b>			
Massachusetts Endangered Species Act (321 CMR 8.00)	Applicable	The Commonwealth of Massachusetts has authority to research, list, and protect any species deemed endangered, threatened, or of other special concern. These species are listed as either endangered, threatened, or species of special concern in the regulations. The Massachusetts lists may differ from the federal lists of endangered species. Actions must be conducted in a manner that minimizes the effect on Massachusetts-listed endangered species and species listed by the Massachusetts Natural Heritage Program.	Alt 1: N/A Alt. 2, 3, & 7: Several state-listed species have been identified in the vicinity of MMR. Areas where work is to be conducted will be evaluated for the presence of habitat for endangered or threatened species. Activities will be designed to meet the requirements of these regulations.

Alt. 1: No Remedial Action with Long-Term Monitoring.

Alt. 2: Institutional and Engineering Controls

Alt. 3: Extraction, Treatment and ReInjection for Plume Capture

Alt. 7: Extraction, Treatment and ReInjection to Capture the Central Portion of the FS-29 Plume



**APPENDIX A Table 6  
FS-29 Plume Action-Specific ARARs**

Requirement	Status	Requirement Synopsis	Action to be Taken to Attain Requirement
<b>Federal Regulations and Guidance</b>			
RCRA - Identification and Listing of Hazardous Wastes; Toxicity Characteristics (40 CFR 261.24)	Relevant and Appropriate	These requirements identify the maximum concentrations of contaminants for which the waste would be a RCRA-characteristic hazardous waste for toxicity. The analytical test given in Appendix II is referred to as the TCLP.	Alt. 1: N/A Alt. 2, 3, & 7: Drill cuttings, spent activated carbon, and sludge sent offsite for disposal (not including regeneration) will be analyzed according to the TCLP. If TCLP results exceed the standards in 261.24, the material will be disposed of offsite in a RCRA-permitted treatment storage and disposal facility.
RCRA Subtitle C, 40 CFR Part 264 - Standards for Owners and Operators of Hazardous Waste Treatment, Storage and Disposal Facilities.	Relevant and Appropriate	These standards, which regulate the operation of facilities that treat, store, or dispose of hazardous waste, take effect through authorized state RCRA programs cited below (Massachusetts HWMR and Hazardous Waste Management Regulations).	Alt. 1: N/A. Alt. 2, 3, & 7: See MA hazardous waste regulations cited below.
RCRA Air Emission Standards for Process Vents (40 CFR 264, Subpart AA)	Relevant and Appropriate	These regulations establish requirements for controlling emissions from process vents associated with treatment processes that manage hazardous wastes with organic concentrations of 10 ppm or more.	Alt. 1 & 2: N/A Alt. 3 & 7: If thresholds are exceeded, emissions from process vents will be controlled in accordance with these requirements.
Standards for Control of Emissions of VOCs, RCRA (40 CFR 264, Subpart BB)	Relevant and Appropriate	Contains air pollutant emissions standards for equipment leaks at hazardous waste TSD facilities. Contains design specifications and requirements for monitoring for leaks. It is applicable to equipment that contains hazardous wastes with organic concentrations of at least 10% by weight.	Alt. 1 & 2: N/A Alt. 3 & 7: If treatment involves groundwater with organic concentrations of at least 10% by weight, equipment will meet design specifications and will be monitored for leaks.

**APPENDIX A Table 6  
FS-29 Plume Action-Specific ARARs**

<b>Requirement</b>	<b>Status</b>	<b>Requirement Synopsis</b>	<b>Action to be Taken to Attain Requirement</b>
Underground Injection Control Program, 40 CFR 144, 146, 147, 1000	Applicable	These regulations outline minimum program and performance standards for underground injection wells and prohibit any injection that may cause a violation of any primary drinking water regulation in the aquifer. Infiltration galleries fall within the broad definition of Class V wells.	Alt. 1 & 2: N/A Alt. 3 & 7: Extracted groundwater will be treated to levels at or below federal and state drinking water standards to ensure that discharges to infiltration galleries will not cause any violation of drinking water standards in the receiving aquifer.
<b>State Regulations</b>			
Massachusetts Air Pollution Control Regulations (310 CMR 7.00)	Applicable	These regulations set emission limits necessary to attain ambient air quality standards.	Alt. 1 & 2: N/A Alt. 3 & 7: Remedial actions (e.g., well drilling and the installation of piping) will be conducted to meet the standards for visible emissions (310 CMR 7.06); dust, odor, construction, and demolition (310 CMR 7.09); noise (310 CMR 7.10); and volatile organic compounds (310 CMR 7.18). If limits are exceeded, emissions will be managed through engineering controls.
Massachusetts HWMR - Requirements for Generators (310 CMR 30.300-30.371)	Relevant and Appropriate	This requirement sets standards for generators of hazardous waste that address (1) accumulating waste, (2) preparing hazardous waste for shipment, and (3) preparing the <i>uniform hazardous waste manifest</i> . Massachusetts specifies requirements for very small quantity generators, as well as small and large quantity generators.	Alt. 1: N/A Alt. 2, 3, & 7: If RCRA-characteristic hazardous wastes are generated, the material will be managed in accordance with these requirements.
Massachusetts Hazardous Waste Management Regulations - Location Standards for Facilities (310 CMR 30.700 - 30.707)	Relevant and Appropriate	There shall be a minimum of 300 feet from the active portion of the facility to the facility property line.	Alt. 1: N/A. Alt. 2, 3, & 7: A waiver may be requested for exemption from the distance requirement from the treatment facility to the property line.

**APPENDIX A Table 6  
FS-29 Plume Action-Specific ARARs**

Requirement	Status	Requirement Synopsis	Action to be Taken to Attain Requirement
Massachusetts Underground Water Source Protection, 310 CMR 27.00	Applicable	Under these regulations, "no underground injection shall be allowed where a Class V well causes or allows movement of fluid containing any pollutant into underground sources of drinking water and the presence of such pollutant causes or is likely to cause a violation of any Massachusetts Drinking Water Regulation ... or ... adversely affects or is likely to adversely affect the health of persons." Class V wells are defined to include "recharge wells used to replenish the water in an aquifer."	Alt. 1 & 2: N/A Alt. 3 & 7: Extracted groundwater will be treated to levels at or below federal and state drinking water standards to ensure that discharges to infiltration galleries will not cause any violation of drinking water standards in the receiving aquifer.

Alt. 1: No Remedial Action with Long-Term Monitoring.

Alt. 2: Institutional and Engineering Controls

Alt. 3: Extraction, Treatment and Reinjection for Plume Capture

Alt. 7: Extraction, Treatment and Reinjection to Capture the Central Portion of the FS-29 Plume

## **APPENDIX B**

### **Simulation of Remedial Alternatives for the FS-28 and FS-29 Plumes Using the SWOU Zoom Model**

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Table B6-2	Performance Summary of Alternatives for the FS-29 Plume
Table B8-1	Performance Summary of Alternatives 4 through 7 for the FS-28 Plume

## ACRONYMS AND ABBREVIATIONS

3-D	three-dimensional
AFCEE	Air Force Center for Environmental Excellence
ASCII	American standard code for information interchange
BuildM1	code to construct MODFLOW input files from geometrical objects
CCl <sub>4</sub>	carbon tetrachloride
CFC	chlorofluorocarbon
CS	chemical spill
EDB	ethylene dibromide (1,2-dibromoethane)
EW	extraction well
FS-28	Fuel Spill-28
FS-29	Fuel Spill-29
ft	feet or foot
ft/day	foot per day
GMS	Groundwater Modeling System
gpm	gallons per minute
IG	infiltration gallery
kg	kilograms
LF-1	Landfill-1
MCL	maximum contaminant level
MODFLOW	USGS finite-difference hydrologic code
MODFLOW/ SURFACT	enhanced version of MODFLOW (HydroGeoLogic 1996)
msl	mean sea level (1927 National Geodetic Vertical Datum)
MT3D	chemical transport code used with MODFLOW

PathT3	particle tracking code that keeps track of the zone (e.g., plume) associated with each particle (HydroGeoLogic Inc.)
PlmSeedV	particle-seeding code that places particles of variable mass and constant volume in the SWOU Zoom Model for tracking using Spltp93
RI	remedial investigation
SD-5	Storm Drain-5
Spltp93	particle-tracking code that keeps track of the mass associated with each particle (HydroGeoLogic Inc.)
SWOU	Southwest Operable Unit
Tecplot	package of two- and three-dimensional plotting utilities
Zoom32	code to add boundary conditions to the Zoom Model from the Regional Model
µg/L	micrograms per liter



## 1.0 INTRODUCTION

Modeling focuses on two plumes: Fuel Spill-28 (FS-28) and Fuel Spill-29 (FS-29). Ethylene dibromide (EDB) is the primary contaminant in each of these plumes. EDB has been detected in the FS-28 plume in the Southwest Operable Unit (SWOU) at levels as high as 18 µg/L. The Massachusetts maximum contaminant level (MCL) for EDB is 0.02 µg/L. The southern part of this plume is already being treated by extraction well-1 (EW-1) (AFCEE 1998) and a system of well points, so remedial alternatives investigated here focus on the upgradient part of the plume near Coonamessett Pond. EDB is less concentrated there, at approximately 3 µg/L. EDB is present in the FS-29 plume at much lower levels, with a maximum concentration of 0.071 µg/L.<sup>1</sup> The FS-29 plume also contains carbon tetrachloride (CCl<sub>4</sub>), co-located with EDB.

Remedial alternatives for the FS-29 plume were first presented in Appendix C of the *Final SWOU Feasibility Study* (FS) (AFCEE 1999a). Two alternatives in addition to the baseline scenario are repeated here: the expedited capture alternative, which focuses on the Chemical Spill 21 (CS-21), CS-20, and CS-4 plumes but also captures a portion of the FS-29 plume, and the FS-29 plume full capture alternative, which addresses all four plumes.

Four new remedial alternatives for the northern part of the FS-28 plume were modeled. They are referred to as Alternatives 4 through 7, continuing with the numbering scheme from the *Final SWOU Feasibility Study* (AFCEE 1999a). Alternative 4 includes two fences of 10 extraction wells each, Alternative 5 includes only the southern fence from Alternative 4, Alternative 6 uses five extraction wells arrayed across the northern part of the plume, and Alternative 7 uses only three extraction wells just south of the western arm of Coonamessett Pond.

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<sup>1</sup> The value presented represents the highest concentration detected in a monitoring well sample. A bore water sample collected from 69MW1536 contained 0.108 µg/L of EDB.

Contaminant concentration data from boreholes and monitoring wells were interpolated to a three-dimensional grid as a preliminary step to particle seeding and an evaluation of flow paths. Kriging produced realistic plume shells that reasonably approximated the hand-drawn outlines and cross-sections presented in the *Final SWOU Remedial Investigation* (AFCEE 1999b). Kriging anisotropies and ranges were adjusted to account for the expected elongation of plumes parallel to the direction of groundwater flow. (Kriging anisotropies are a statistical property unrelated to anisotropies in hydraulic conductivity.) Statistical artifacts in regions lacking observations were truncated to manually interpreted plume outlines. The kriged concentration arrays were used to control the location of seeds for particle tracking. The particle-seed locations were compared with the SWOU Zoom Model grid; any particles that lay below the bottom of the model were discarded. Each particle represents a constant volume of groundwater; variations in EDB concentration are reflected in variations in mass assigned to each particle. The final particle sets provide the best available estimates of plume masses.

Remedial alternatives were evaluated using the SWOU Zoom Model to calculate particle trajectories. Throughout most of the model, modeled plume trajectories closely match plume trajectories inferred from plume geometries and probable source histories. Known difficulties with the model near the EW-1 extraction well in the southern part of the FS-28 plume do not affect the northern part of the FS-28 plume or the FS-29 plume, the areas of interest for this modeling effort.

## **2.0 SIMULATION SOFTWARE AND GROUNDWATER MODEL**

### **2.1 HYDROLOGIC MODELING SOFTWARE**

Modeling software used to create and run the SWOU Zoom Model and visualize the results was the same as that used for the 1999 Regional Model (Appendix B in AFCEE 1999a). The software has also been discussed in the SWOU FS (Appendix C in AFCEE 1999a) and is outlined here. The model was created with BuildM1 (developed by HydroGeoLogic for AFCEE) using the geometrical description of

slabs and lenses from the 1999 Regional Model, but with finer discretization. Zoom32 (developed by HydroGeoLogic for AFCEE) was used to assist in grid refinement and to create alternative-specific well files. Extraction wells specified in terms of site coordinates, screen elevations, and pumping rates are interpolated onto the zoom model grid by Zoom32. Zoom32 was also used to interpolate boundary conditions. Finally, steady-state heads and flows were calculated using MODFLOW/SURFACT (HydroGeoLogic 1996).

Extraction-well effectiveness was evaluated by particle tracking using Spltp93 (developed by HydroGeoLogic for AFCEE). Validation of Spltp93 was discussed in the SWOU feasibility study (Appendix B in AFCEE 1999a). Spltp93 offers several post-processing options: (1) tracking the mass arriving at each extraction cell and (2) providing snapshots of mass distribution and particle locations at specified time intervals. It also provides particle tracks formatted for visualization in Tecplot (Amtec Engineering 1998).

For particle accounting, Spltp93 was run using its built-in analytical solution to determine the radius of capture of each extraction well cell-by-cell along its length. To accomplish this, the extraction wells are considered to be placed at the center of each cell through which they pass, resulting in offsets between their specified coordinates and their actual locations by as much as half the size of the model grid spacing. Because the SWOU Zoom Model grid in this area has a spacing of 132 feet, offsets could be as much as  $\pm 76$  feet in either the x and/or y directions. Because no cell contains more than one well, and because the minimum inter-well spacing is more than 175 feet, these offsets are not significant in the scope of this analysis.

During the course of this investigation, it became apparent that Spltp93 was categorizing particles as “trapped” when in reality they were merely stalled near an extraction well due to a numerical artifact in the particle-tracking algorithm. As some particles approached an extraction well from downgradient (in a regional sense), clearly indicating that they had already been captured, their velocities dropped to zero a short distance (usually less than 100 feet) from the well. This is a consequence of

the radial flow patterns induced by the extraction wells. In a cell containing an extraction well, Spltp93 interpolates the velocity at points within the cell by a distance-weighted average of the velocities across each face of the cell. Thus, because of the convergent flow field, the interpolated velocity will be zero at certain locations. The regional groundwater velocity field causes these locations to be displaced downgradient of the center of the cell, producing the observed stalled particles. To correct this, Spltp93 was modified to check for nearby extraction wells. If there were one or more extraction wells within a specified distance (1000 feet was used), a “trapped” particle was assumed to be captured by the nearest extraction well. Changes to Spltp93 are documented more fully in the source code and in Spltp93.doc (both maintained at the Jacobs Engineering Albuquerque office).

Spltp93 also appears to be double-counting some particles during categorization, so that the sum of the masses extracted, exiting to surface water, and remaining in groundwater at the end of the simulation period exceeded the initial mass. The extent of double counting was similar to the amount classified as discharged to Coonamessett Pond. Time constraints during this investigation did not permit a detailed study of this problem, so the excess mass was distributed proportionally among each of the categories. This was achieved by adding the mass excess to the initial mass, with the effect of re-normalizing the calculation of percentages. An examination of animations of particle movement in side view suggests that Spltp93 may be overstating the mass discharging to Coonamessett Pond, a bias that still remains after re-normalization.

## **2.2 PARTICLE SEEDING**

Plume shells were interpolated from field data to a regular three-dimensional (3-D) grid using the kriging package in the Groundwater Modeling System (GMS) (EMS-i 1999). The resulting gridded concentration distributions were re-interpolated to another regular 3-D grid of particles using PlmSeedV (developed by Jacobs Engineering for AFCEE). These particles are referred to as constant-volume particles because the volume of aquifer represented by each one is the same. The particles

differ in their masses, determined from the volume-weighted average contaminant concentrations in the volume represented by each particle. PlmSeedV also compares particle locations with the MODFLOW/SURFACT model domain and eliminates any particles lying outside, above, or below the model. PlmSeedV was validated by comparing seed locations and mass distribution with 3-D plume shells, and by verifying that the sum of the masses of all seeds was equal to the mass represented by the interpolated plume. The particles are tracked forward in time, using Spltp93 to show plume evolution under various remedial activities. Results were visualized and animated using Tecplot (Amtec 1998).

### **2.3 DESCRIPTION OF THE SWOU ZOOM MODEL**

The SWOU Zoom Model approximately encompasses the southwestern quadrant of the 1999 Regional Model, extending from Falmouth and Buzzards Bay in the southwestern corner to Snake Pond in the northeastern corner. The boundary and grid of the SWOU Zoom Model are illustrated in Figure B-1. Vertical discretization is the same as that in the 1999 Regional Model, consisting of 21 layers ranging in thickness from 4 feet near the top of the model to 50 feet in the bottom layer. Layer 1 includes an extra 20 feet of unsaturated head space to allow for potential variations in the height of the water table resulting from remedial activities. Lateral discretization ranges from 660 feet near the edges of the model and, in regions lacking contaminant plumes, down to 132 feet across most of the SWOU and adjacent plumes (i.e., Landfill-1 (LF-1), Chemical Spill-10 (CS-10), Storm Drain-5 (SD-5), and Ashumet Valley). There are 954,912 cells in the model, of which approximately 80 percent are active.

Boundary conditions are inherited from the 1999 Regional Model. The model is bordered by constant-head boundaries with heads of 0 feet mean sea level (msl) along the coastline and heads from the steady-state solution of the 1999 Regional Model elsewhere. Rivers are represented by drain cells. Because of the finer discretization in parts of the model, Zoom32 mapped some drains in the 1999 Regional Model onto multiple cells in the SWOU Zoom Model. These drains were manually edited to

conform as closely as possible to the course of the rivers while preserving the same total conductance that was present in the regional model. Background pumping and recharge is the same as in the 1999 Regional Model. Because these simulations look forward in time, there is no recharge from the Ashumet Valley sewage treatment plant. Although the SWOU plumes are somewhat isolated from neighboring plumes, the final design of a selected remedial alternative must consider potential side effects from remedial actions in those plumes.

## **2.4 PERFORMANCE OF THE SWOU ZOOM MODEL**

Performance of the SWOU Zoom Model has been discussed in detail and illustrated in Appendix B of the SWOU FS (AFCEE 1999a). The important features are summarized below.

Particles representing the CS-21 and FS-29 plumes track too much to the west, showing less curvature than the probable trajectory implied by the plume outlines. The tracks are parallel to the plume axes near the downgradient ends of the plumes. The western bias in flow directions inherent in the model is a constant factor that does not interfere with the evaluation of the relative merits of remedial activity, but would need careful consideration in the design of any actual extraction system.

North of the western arm of Coonamessett Pond, particle trajectories in FS-28 lie parallel to the plume axis, indicating satisfactory performance of the model in this area. The northern part of the plume is the focus of the remedial alternatives presented in this feasibility study for FS-28.

Particles seeded across the midpoint of the FS-28 plume, south of the western arm of Coonamessett Pond, discharge rapidly to the Coonamessett River, but show an arcuate trajectory with a westerly trend as they head south. This trajectory largely bypasses the FS-28 EW-1 extraction well. Both the plume outline and the EW-1 Zoom Model (AFCEE 1998) suggest that the actual plume trajectory is directly south, with the EW-1 extraction well properly sited to intercept a major portion of the

plume. Thus, the SWOU Zoom Model is not appropriate for detailed simulations of the southern part of the FS-28 plume. However, westerly bias in flow directions north of the western arm of Coonamessett Pond is minimal and does not significantly affect simulations of remedial alternatives there.

Modeled groundwater velocities in the vicinity of the FS-28 plume also appear to be too slow. In the baseline scenario, discussed in detail later on, the model travel time for particles at the trailing edge of the plume to reach the EW-1 extraction well or discharge to the Coonamessett River is 73 years, corresponding to a velocity of 0.35 foot per day (ft/day). This low value is a consequence of the low horizontal hydraulic conductivity ( $K_h$ ) and very low vertical hydraulic conductivity ( $K_v$ ) assigned to the deeper portions of the aquifer near the FS-28 plume. In contrast, several lines of physical evidence, discussed in the SWOU RI (AFCEE 1999b) suggest that groundwater velocities ( $v_h$ ) associated with the FS-28 plume are approximately 1.4 ft/day:

- Darcy's Law, based on gradients ( $i_h$ ) and  $K_h$  inferred from pump tests, slug tests, and grain size. Using a porosity ( $n$ ) of 0.3,  $K_h = 210$  ft/day, and  $i_h = 0.002$  ft/ft,  $v_h = K_h * i_h * n = 1.4$  ft/day.
- USGS age analysis of FS-28 groundwater based on chlorofluorocarbons and  $^3\text{H}/^3\text{He}$  measurements gave values of 46 years at the leading edge of the plume and 28 years at the trailing edge. Presuming that the plume originated 13,000 feet upgradient of the trailing edge (24,000 feet upgradient of the leading edge), an average groundwater velocity of 1.3 to 1.4 ft/day is required.
- Based on knowledge of activities at MMR, the age of FS-28 is estimated to be 50 years. The presumed area of infiltration is 24,000 upgradient of the leading edge, implying a groundwater velocity of 1.3 ft/day.

For these reasons, a scaling factor equal to the ratio of the model velocity to the physical velocity ( $0.35 \text{ ft/day} / 1.4 \text{ ft/day} = 0.25$ ) is used in this appendix to obtain realistic estimates of remediation times for FS-28 remedial alternatives. Scaled times are referred to as "corrected" times throughout the remainder of this appendix.

Groundwater velocities in the vicinity of FS-29 have not been rigorously evaluated, but the difference between the model and actual flow rates is probably much smaller.

Here, there is no strong decrease in horizontal hydraulic conductivity with depth; horizontal hydraulic conductivities remain high to the bottom of the aquifer. For this reason, no scaling factor has been applied to model results for the FS-29 plume.

### **3.0 PLUME REPRESENTATIONS AND PARTICLE SEEDING**

Development of an accurate representation of each plume with respect to the SWOU Zoom Model grid was a complex process because of limitations inherent in the 3-D interpolation module in GMS (EMS-i 1999). GMS can accurately interpolate to 3-D grids, including MODFLOW/SURFACT grids, where spacings in the x and y directions are variable. However, GMS does not make use of the top and bottom elevations stored in the MODFLOW/SURFACT \*.bcf and so cannot accurately interpolate to a grid with variable layer thicknesses, such as that of the SWOU Zoom Model.

#### **3.1 INTERPOLATION OF OBSERVATIONS TO A THREE-DIMENSIONAL GRID**

The scattered field measurements of contaminant concentrations must be interpolated to a regular 3-D grid before particles can be seeded. A comparison of various interpolation algorithms available in GMS showed that kriging could provide the most realistic-looking results. Because the data are sparsely distributed, rigorous geostatistically defensible variograms are not obtainable. Thus, kriging is a qualitative tool. The appropriateness of the resulting plume shells is judged by their visual appearance and hydrologic plausibility.

Development of a 3-D plume shell of concentrations interpolated to a 3-D regular grid followed these steps:

- Divide the area of detected contamination into domains of uniform groundwater flow direction. This allows the interpolation parameters to simulate the elongation of the plumes in the direction of groundwater flow. Separate domains are needed to accommodate the varying azimuth of anisotropy for kriging. The anisotropy qualitatively accounts for the predominance of longitudinal dispersion relative to transverse or vertical dispersion during transport.



- Establish a convenient regular 3-D grid. For the SWOU, a grid large enough to encompass all of the plumes was used, permitting the interpolated plumes to be combined in various permutations for subsequent analysis. Interpolated data were manipulated using the data calculator in GMS. The origin of the grid was at 844100 easting, 218700 northing, with a rotation of 11 degrees counter clockwise to match the SWOU Zoom Model grid. The grid extended 19300 feet in the x direction divided into 97 cells, 18900 feet in the y direction divided into 95 cells, and from 75 feet msl to -250 feet msl in the z direction divided into 25 cells. The grid contained 230375 cells, with dimensions of 198.9 feet by 198.9 feet by 13 feet.
- Interpolate each domain onto the 3-D grid. Nomenclature of parameters in the following discussion follows GMS usage. A spherical variogram function was used. The principal axis of the variogram was aligned with the direction of groundwater flow by adjusting the azimuth angle. The nugget effect was set to 0. The default value for the contribution (sill value) was used, a value that was different for each set of observed contaminant concentrations. A range of 3000 feet was used in all cases. The range corresponds to the distance at which the influence of each point on the interpolated value drops to zero. Anisotropy values perpendicular to groundwater flow of 0.3 horizontally and 0.005 vertically were used in all cases. The anisotropy is a coefficient for the range in the stated directions. Search parameters used similar values for azimuth and anisotropy. The maximum search radius was set equal to the range, so that the interpolated value tended toward zero in areas of little data coverage.
- Use the GMS map module to create a mask for each domain. The mask serves to eliminate artifacts of the kriging process that would otherwise produce hydrologically unreasonable extensions of a plume into areas of no data coverage. The mask is the plan view of the maximum lateral extent of contamination present at more than one-fifth of the MCL. It contains values of one within a plume and values of zero elsewhere. The mask was mapped onto the 3-D grid via the MT3D initial-concentration array, and then converted into a GMS ASCII data set. The corresponding interpolated concentrations were also converted to a GMS ASCII data set. A small program was written to step through the two data sets simultaneously; it retained the interpolated concentration value when the mask value was one, and set the concentration to zero when the mask value was zero.
- Import the masked concentration array back into GMS for visualization as a series of isosurfaces. Notice that at this point the concentration array has not been compared to the SWOU Zoom Model grid, so that in some cases the visualized plume shells may extend to greater depths than the model grid.

Because of the averaging effect of the kriging process, the maximum interpolated value was typically 10 to 20 percent less than the maximum observed concentration. The kriging algorithm implicitly assumes that sufficient data have been collected to statistically define the distribution of values within zones of contamination. For the

SWOU plumes, this condition is not met for the high-concentration outliers of the distributions. Instead, such points are smoothed and lowered as they are averaged with their nearest neighbors. Thus, the raw results of kriging tend to underestimate the highest concentrations, and hence the contaminant mass, present in the plumes. To offset this tendency, a conservative approach has been used here, in which, after kriging, all of the interpolated values are scaled by the ratio of the highest observed value to the highest interpolated value. This forces a match between the highest observed and interpolated values, but probably tends to overestimate the mass of the plume. Because of these concerns, the kriging process probably generates an uncertainty of  $\pm 10$  percent in estimates of total plume mass. This is less than the uncertainty related to the distribution of observed concentrations and choice of kriging parameters. The total uncertainty in plume mass is probably on the order of  $\pm 25$  percent.

### **3.2 PARTICLE SEEDING FOR TRANSPORT ANALYSIS**

Particles for transport analysis were seeded based on concentrations in the masked concentration array using the PlmSeedV program. PlmSeedV performs the following operations: (1) reads the concentration array, (2) allows the user to specify the number of particles in the x, y and z directions, (3) calculates the mass associated with each particle for those particles within specified concentration limits, (4) reads the SWOU Zoom Model grid, and (5) writes out the location and mass of each particle contained within the SWOU Zoom Model grid. PlmSeedV also provides summary statistics, such as total number of particles seeded and minimum and maximum concentration. For the SWOU plumes, the number of particles along the x, y and z axes of the concentration array were 146, 146, and 22, respectively. This produced a particle spacing of approximately 132, 130, and 15 feet in the respective directions.

Seeding using constant-volume variable-mass particles permits simulation of remedial alternatives with a relatively small number of particles. The alternative of constant-mass particles results in very high particle density at hot spots within a

plume if low-mass particles are used, or results in the loss of the low-concentration fringes of the plume if high-mass particles are used. The trade-off is that a massive constant-volume particle might escape because it sits on an uncaptured flow line, even though most of the mass it represents sits on captured flow lines. This would lead to excessive conservatism in analysis of the remedial alternative. Such a bias is unlikely to be present in the scenarios discussed below because extraction efforts focus on the cores of the plumes, capturing all of the highest-mass particles and most of the surrounding low-mass particles. Any statistical aberrations due to captured versus uncaptured flow lines are small because the masses of the potentially affected particles are small.

### **3.3 PLUME MASSES BASED ON CONCENTRATIONS EXCEEDING THE MCL**

The mass of EDB in the FS-28 and FS-29 plumes are summarized in Table B3-1. The masses represent groundwater in which the contaminant concentration exceeds the MCL for drinking water (i.e., 0.02 µg/L for EDB).

The FS-28 plume is heavily contaminated, with an average concentration of 0.71 µg/L, a level that exceeds the MCL by a factor of 36. In contrast, the FS-29 plume has an average concentration of 0.037 µg/L, less than a factor of two greater than the MCL. The FS-28 plume is the largest (by volume) in the SWOU, with 580 million cubic feet of contaminated water represented by 7527 particles. In comparison, the volume of the FS-29 plume, with 150 million cubic feet of contaminated water represented by 1997 particles, is similar to that of the nearby CS-21, CS-20, and CS-4 plumes. This suggests that similar effort would have to be expended to extract the contaminated water in the FS-29 plume although its degree of contamination (by mass) is much lower than the CS-21, CS-20, or CS-4 plume.

### **3.4 PLUME GEOMETRIES AND COMPARISON TO THE SWOU RI**

Plume outlines in plan view and side view are presented in Figures B-2 and B-3 for FS-28 and FS-29, respectively. The MCL isosurfaces in plan view closely match the

plume outlines in the SWOU RI (Figure 4-23 in AFCEE 1999b), which were contoured manually at the MCL. In general, the interpolated surfaces presented here show more small-scale irregularities than manually interpreted outlines and cross-sections. Kriging builds the plume from a series of flattened ellipsoids around each of the comparatively sparsely distributed measurement points. The stacked ellipsoids only partially overlap, imparting a lumpy appearance to the isosurfaces. Although this results in some differences in interpretation along the low-concentration margins of the plumes, the high-concentration cores appear to be reasonably represented by the interpolated plumes.

The interpolated FS-28 plume, shown in Figure B-2, contains nearly all of the EDB present in groundwater in the SWOU (11.72 kg), and is delineated by isosurfaces of 0.02, 0.5, and 2.5  $\mu\text{g/L}$ . It is based on data collected in late 1996 and early 1997 and a few more recent samples from monitor wells near the FS-28 EW-1 extraction well. It does not reflect the effects of ongoing extraction at EW-1, which commenced operation in October 1997. Representation of the leading edge of the plume differs significantly from the manually interpreted plume outline presented in the SWOU RI (Figure 4-30 in AFCEE 1999b). Groundwater here is discharging to bogs along the Coonamessett River, with a strong upward component to the groundwater flow direction. This is not reflected in the kriging parameters, which are the same as elsewhere in the plume, with a horizontal principal axis aligned in azimuth with the plume axis. The resulting inaccuracy is inconsequential, however, because the leading edge contains low concentrations that quickly reach discharge zones, as was shown by the EW-1 Zoom Model (AFCEE 1998). When the interpolated plume shell was compared to the SWOU Zoom Model grid by PlmSeedV, 13 percent of the mass lay below the bottom of the model and was removed (i.e., not included in the particle seeds or mass summary). In addition, a significant portion of the lower part of the plume shell shown in Figure B-2 lies below the bedrock-aquifer interface. This plume shell should be truncated at the bedrock surface, but the project schedule did not permit writing the necessary software to accomplish this.

The interpolated FS-29 plume shown in Figure B-3 differs significantly from the manually interpreted outline in the SWOU RI (Figure 4-25 in AFCEE 1999b). The interpolated plume is based only on the EDB data set, whereas the manually interpreted plume used both EDB and CCl<sub>4</sub>. Because of this, the lower lobe of the manual plume outline was interpreted to extend at least as far downgradient as the upper lobe. The lower lobe of the interpolated plume, at depths of -200 to -250 feet msl, is restricted to the upgradient half of the plume. Therefore, the estimated mass of EDB is approximately 25 percent lower than if CCl<sub>4</sub> detections had been included in the kriging process. The mass and extent of the modeled plume should be updated for any final remedial treatment system design, but are adequate for purposes of this FS. The leading edge of the upper lobe of the interpolated plume was extrapolated by the kriging algorithm approximately 1500 feet further downgradient than the plume shown in the manual outline because of an absence of bounding measurements at the depth of the plume. Since the completion of the SWOU RI, additional data have defined the leading edge of the plume, but have not been incorporated in the plume shell. Only a single isosurface is portrayed in Figure B-3, reflecting the low total mass (0.16 kg) and low average concentration (0.037 µg/L) of EDB in this plume. When the interpolated plume shell was compared to the SWOU Zoom Model grid by PlmSeedV, 16 percent of the mass lay below the bottom of the model and was removed (i.e., not included in the particle seeds or mass summary). Also, a significant portion of the lower part of the plume shell shown in Figure B-3 lies below the bedrock-aquifer interface. This plume shell should be truncated at the bedrock surface, but the software for this has not been developed.

In summary, the interpolated plume shells capture the major features of the contaminant plumes with some minor deviations at the upgradient and downgradient fringes. In these areas, the kriging algorithm tends to extrapolate further from high-concentration observations than the manually interpreted plume outlines. In contrast, observations that barely exceed the MCL are sometimes excluded at the fringes of the plume. Probably the net effect is to slightly over-estimate the masses of the plumes and their extents at certain depths while underestimating their extents at other depths. These variances must be fully evaluated in any final design.

#### 4.0 BASELINE PLUME TRAJECTORIES

The baseline scenario, listed in Table B4-1, consists of wells inherited from the 1999 Regional Model (SWOU FS Appendix B) plus the existing remediation systems in the SWOU. These are the FS-28 EW-1 extraction well and the CS-4 extraction wells and infiltration gallery. Treated water from FS-28 EW-1 is released to the Coonamessett River and does not enter into the groundwater model. The major wells in the vicinity of FS-28 are illustrated in Figure B-4. Not shown are some minor irrigation wells along the Coonamessett River.

In the absence of active remedial measures such as pump-and-treat or recirculation wells, the contaminant plumes will continue to be advected by groundwater, eventually reaching discharge zones such as bogs, rivers, or the ocean. The projected plume trajectories for the FS-28 and FS-29 plumes are illustrated in Figure B-5. This figure shows simulated particle positions for each plume for elapsed model times of 10, 30, 60, and 100 years (corresponding to 2.5, 7.5, 12.5, and 25 years corrected time for the FS-28 plume). Only advective transport is simulated with no allowance for retardation or degradation. The present position of the plumes relative to their probable source areas suggests that retardation of EDB is negligible in the western Cape Cod aquifer (see SWOU FS Appendix B Figure 25). Otherwise, simulated particle tracks from source areas would have overshoot the present plume positions after the 30 to 40 years available for migration.

Particles representing EDB in the FS-28 plume (Figure B-5) discharge rapidly to the upper reaches of the Coonamessett River. As shown in Table B4-2, only half of the plume mass remains in groundwater after 2.5 years (corrected time). A few particles follow the course of the Coonamessett River in plan view, moving along the bedrock-aquifer interface. These may eventually discharge to the lower Coonamessett River, but remain in groundwater at the end of the 25-year (corrected time) simulation. This behavior is likely an artifact of the model rather than a realistic prediction. Realistically, these particles probably discharge to the upper Coonamessett River with the rest of the plume. Many of these particles represent relatively large contaminant masses and account for 15 percent of the original plume mass.

Particles representing EDB in the FS-29 plume (Figure B-5) continue on their west-southwesterly trajectories and begin to discharge to Buzzards Bay after approximately 25 years. As with the CS-21 plume, there is no evidence here of the westward bias suggested by the SWOU particles in Figure B-5. However, particles in the upgradient portion of the plume do not follow those in the downgradient portion, but instead track further south where they are slowed by the low hydraulic conductivity that characterizes the deep aquifer. As shown in Table B4-2, 79 percent of the plume remains in groundwater after 30 years, gradually decreasing to 28 percent after 100 years.

## **5.0 REMEDIAL ALTERNATIVES FOR THE NORTHERN FS-28 PLUME**

Four new remedial alternatives for the northern part of the FS-28 plume have been modeled. They are referred to as Alternatives 4 through 7 and were designed to capture the portion of the FS-28 plume north of the western arm of Coonamessett Pond. All baseline wells are included in these alternatives. As much as possible, wells for each alternative have been sited along roads in an effort to minimize potential access problems. All reported times are corrected for unrealistically slow advection in the vicinity of FS-28, as discussed in Section 3.1.

### **5.1 CONFIGURATION OF ALTERNATIVES**

Initial well layouts for each alternative were developed in plan view in conjunction with the regulatory community. Screen intervals were set to encompass the thickness of the kriged 3-D plume at each location, as determined from representative cross-sectional slices through the plume. The kriged plume, described previously, is known to exaggerate somewhat the vertical extent of the plume. Nevertheless, the kriged plume is the appropriate target for screen intervals because it is the basis of seeding for the particles used to visualize the effects of each alternative.

Alternatives 4, 6, and 7 were optimized after an initial run by shortening the screen intervals to exclude any length of screen intercepting only clean water. Alternatives 6

and 7 were judged sufficiently optimized after two runs, whereas Alternative 4 required three runs. Alternative 5 was created from the optimized southern fence of Alternative 4, and was not subjected to further optimization. Final configuration of each alternative follows.

- Alternative 4 consists of two fences of 10 extraction wells each, as shown in Figure B-6. The southern fence runs across the plume immediately north of the western arm of Coonamessett Pond, and the northern fence at the northern end of Coonamessett Pond cuts across the eastern two-thirds of the plume. A single line of eleven injection wells slightly downgradient of the extraction wells completes the southern fence, whereas injection wells for the northern fence are split into two groups. A group of four lies along the eastern edge of the plume near the southern fence, and a group of six lies across the northern end of Coonamessett Pond. Coordinates, screened intervals, and flow rates for Alternative 4 wells are listed in Table B5-1. The combined extraction rate for both fences is 600 gpm, apportioned according to the screened length of each well. All extracted water is treated and reinjected.
- Alternative 5 consists of the southern fence of Alternative 4, with a pumping rate of 400 gpm. Because this extraction is distributed among only 10 wells, the rate of extraction per well is somewhat greater than in Alternative 4. The configuration for Alternative 5 is illustrated in Figure B-7, and coordinates, screened intervals, and flow rates are listed in Table B5-2. All extracted water is treated and reinjected.
- Alternative 6, illustrated in Figure B-8, consists of five extraction wells arrayed across the northern FS-28 plume west of Coonamessett Pond. The total extraction rate is 600 gpm, apportioned according to screen length. After treatment, all water is reinjected at three wells immediately north of the western arm of Coonamessett Pond. Coordinates, screened intervals, and flow rates are listed in Table B5-3.
- Alternative 7, illustrated in Figure B-9, consists only of three extraction wells sited along the southern shore of the western arm of Coonamessett Pond. The total extraction rate is 600 gpm, apportioned according to screen length, but none is returned to the subsurface. Half of the treated water is returned to Coonamessett Pond, re-entering the modeled groundwater flow system, while the remaining water is discharged to the Coonamessett River, removing it from the model (recharge from a river to groundwater cannot occur when rivers are modeled as drains). Coordinates, screened intervals, and flow rates are listed in Table B5-4.



## 5.2 EVALUATION OF ALTERNATIVES

Each of the alternatives was evaluated by particle tracking. Particle locations were cataloged as a function of time to provide quantitative estimates of mass captured by extraction wells, discharged to Coonamessett Pond, or remaining in groundwater. The evolution of the plume for each alternative was also animated in plan view and side view. Animations are scaled by simulation step number; one simulation step is equal to one year of model time or approximately 0.25 year of corrected time. Each animation contains 50 steps, spanning 12.5 years of corrected time.

The particle seed file used here for the animations is a subset of the EDB seed file used in the SWOU FS (AFCEE 1999a), consisting only of those particles contained within the outline of the FS-28 plume. As in the SWOU FS, particles were seeded on a grid with x, y, and z spacings of 132.2, 129.2, and 14.77 feet. Thus, the volume of the aquifer represented by each particle is the same, with the mass assigned to each particle equal to the EDB concentration integrated over the volume. The total number of particles seeded was 7527, representing 11.72 kg of EDB in 4270 million gallons of water (assuming a porosity of 0.3). These particles were also used to evaluate the duration of contaminant removal by the FS-28 EW-1 system.

For evaluating the remedial alternatives quantitatively, a second seed file consisting only of those particles north of a northing of 228000 was used, as shown on Figure B-4. This limit is just north of the southern fence for Alternative 4. The total number of particles seeded was 3116, representing 1.541 kg of EDB in 1768 million gallons of water, 13.1 percent of the total mass and 41.4 percent of the total volume of the FS-28 plume. This set of particle seeds will be referred to as the northern FS-28 plume.

In addition to the animations, each scenario is summarized with a figure showing drawdown (Figures B-10 through B-13) and cumulative mass extracted (Figures B-14(a) through B-14(d)). All reported times are corrected for unrealistically slow advection in the vicinity of FS-28, as discussed in Section 3.1.

### **5.2.1 Baseline Scenario**

By definition, drawdown in the Baseline Scenario is zero because it is the reference case against which water tables from the various remedial alternatives are compared. The cumulative mass-capture curves (dashed curves in Figure B-14) show that 20.8 percent of the plume discharges to Coonamessett Pond over the first 11 years of the simulation. Additionally, much of the northern plume is eventually captured by the FS-28 EW-1 extraction well, reaching 42 percent at approximately 12.5 years, but still exhibiting an increasing trend. This estimated capture is extremely conservative because of the westward bias of particle trajectories in the model compared with the actual groundwater system. In reality, FS-28 EW-1 may capture essentially all of the plume that does not discharge to Coonamessett Pond. After 12.5 years, only some scattered low-mass particles remain north of the western arm of Coonamessett Pond.

### **5.2.2 Alternative 4**

As shown in Figure B-10, the predominant effect on the water table by Alternative 4 is a small amount of mounding immediately north of the western arm of Coonamessett Pond. The magnitude of mounding reaches 0.5 foot locally along the line of injection wells for the southern fence. The area over which mounding exceeds 0.1 feet is restricted to the vicinity of the southern fence plus injection wells 1 through 4 of the northern fence. Mounding occurs here because reinjection exceeds extraction; the flow contributed by the four injection wells from the northern fence is derived at a distance, from the northern fence. For the same reason, up to 0.2 foot of drawdown occurs in the western half of the northern fence. Because there are no wetlands in this area, these changes in the water table are inconsequential.

Cumulative mass removal versus time, Figure B-14(a), indicates that 4.5 percent of the northern plume discharges to Coonamessett Pond, nearly all within the first three years. Of the remaining mass, all but 0.3 percent is captured by the extraction wells. Extraction is 95 percent complete after 7.8 years.

The modeling indicates that the northern fence finishes extracting contaminated groundwater within 5.5 years, and the southern fence finishes in about 7 years. In side view, in comparison with the baseline animation, the effect of extraction within the core of the plume and reinjection near the surface is immediately apparent. The remedial system introduces a downward component to the trajectory of the plume, rapidly driving it deeper than its present distribution. This drives the plume far below the capture zone of the Coonamessett water supply well, which is located just south of the western arm of Coonamessett Pond.

### **5.2.3 Alternative 5**

The pattern of mounding induced by Alternative 5, Figure B-11, closely resembles that of the southern fence of Alternative 4, but with maximal values of only 0.4 foot. There is no surface drawdown because all extraction occurs at depth within the body of the plume and is balanced by nearby injection. As in Alternative 4, one result of this geometry is a strong vertical gradient driving the plume downward. Because there are no wetlands in this area, these changes in the water table are inconsequential.

Cumulative mass removal versus time, shown in Figure B-14(b), shows somewhat greater discharge to Coonamessett Pond, reaching 10 percent by 6 years. Of the remaining mass, essentially all is captured by the extraction wells. Extraction is 95 percent complete after 6.5 years, although a small amount of mass continues to be extracted for the remainder of the simulation. Surprisingly, this alternative reaches completion more rapidly than Alternative 4, although less mass reaches the extraction wells and more mass discharges to Coonamessett Pond.

A comparison of animations for Alternative 5 to those of Alternative 4 shows that Alternative 5 is slower, as would be expected because it lacks the northern fence of extraction wells. In Alternative 5, all of the cyan particles north of the extraction wells are gone after 8.5 years, whereas this occurs after 7 years in Alternative 4.

#### **5.2.4 Alternative 6**

The drawdown map for Alternative 6, Figure B-12, shows the effect of using only three shallow injection wells instead of 11 as in Alternative 5 to handle 50 percent more water. Predicted mounding in the vicinity of the injection wells exceeds 1 foot, but the current model is too coarse for accurate prediction in the vicinity of the wells themselves. Deeper wells with longer screens might be needed if this alternative were to be implemented.

Cumulative mass removal versus time, Figure B-14(c), shows minimal discharge to Coonamessett Pond, reaching only 2.9 percent after 3 years. Of the remaining mass, essentially all is captured by the extraction wells. Extraction is 95 percent complete after 4 years, although a small amount of mass continues to be extracted for the next 6 years. This alternative is the most rapid, which is a consequence of the dispersal of extraction-well locations throughout the northern plume and of the comparatively high pumping rate (600 gpm).

The animations for this alternative are consistent with the cumulative-mass-removal curve, which shows removal of all cyan or more massive particles from the northern plume within 5.7 years. As in the other alternative, shallow reinjection produces a downward component to the plume trajectory driving the plume far below the level of the Coonamessett water supply well.

#### **5.2.5 Alternative 7**

Drawdown for Alternative 7, Figure B-13, are predicted to be extensive. The maximum drawdown of the water table is predicted to be slightly greater than 0.6 foot near the westernmost extraction well. The 0.2 foot drawdown contour has a radius of approximately 4000 feet cross-gradient, encompassing the three large ponds nearby (Coonamessett Pond, Crooked Pond, and Deep Pond). Only half the extracted water is returned to the groundwater system via Coonamessett Pond; the remaining water (300 gpm) is discharged to the Coonamessett River. Stage measurements (AFCEE

1999a) suggest that the uppermost reach of this river loses water to groundwater, so increasing the flow may result in increased recharge. However, the model does not permit any return flow from rivers, so the estimated drawdown is probably greater than the actual drawdown if this alternative were to be implemented.

Cumulative mass removal versus time, Figure B-14(d), shows some discharge to Coonamessett Pond, reaching 10.3 percent after 6 years. Of the remaining mass, essentially all is captured by the extraction wells. Extraction is 95 percent complete after 9 years, although a small amount of mass continues to be extracted for the remainder of the simulation. No mass is extracted before 1.2 years because the northern-plume particle set is used to compile performance statistics; the southern edge of this particle set is approximately 1000 feet north of the Alternative 7 extraction wells.

The animations for this alternative are consistent with the cumulative-mass-removal curve, showing removal of most of the mass from the northern plume within 12.5 year simulation period. In side view, it is evident that the vigorous extraction near the base of the aquifer creates a strong downward gradient, completely capturing essentially all of the northern plume. This very effectiveness suggests that the pumping rate might be reduced somewhat and still maintain adequate capture.

## **6.0 ALTERNATIVES FOR THE FS-29 PLUME**

Two active remediation alternatives from the SWOU FS (AFCEE 1999a) are presented here, with emphasis on their effect on the FS-29 plume.

- The expedited capture alternative focuses on capture of the CS-4, CS-20 and CS-21 plumes. In this alternative, the remedial wells in the CS-21 plume also capture the upgradient portion of the FS-29 plume.
- The FS-29 full capture alternative is similar to the expedited capture alternative, and also includes two extraction wells in the toe of the FS-29 plume to achieve nearly complete capture of that plume.

Well locations and pumping rates for these alternatives are listed in Table B6-1, and are illustrated in Figure B-15 and B-16. All baseline wells other than the CS-4

extraction wells are included in these alternatives. The existing CS-4 extraction wells are replaced with wells more suitably located.

Details of the design process and site considerations for these alternatives are available in the SWOU FS Appendix C (AFCEE 1999a). The shallowest wells are located at least 50 feet below the water table and produce negligible drawdown (less than 0.5 foot) at the water table. Treated water is returned to the aquifer via shallow infiltration galleries (IGs), as indicated in Figures B-15 and B-16. For a return flow of 600 gpm, mounding is less than 5 feet with a radial extent of approximately 1000 feet. Because the land surface is at an elevation near 100 feet msl and the water table is below 50 feet msl, such mounding poses no threat to wetlands, ponds, or structures. Any actual implementation of infiltration galleries would require site-specific data to ensure adequate infiltration rates. The presence of less-permeable horizons in the unsaturated zone could affect the geometry of groundwater mounding or even create locally perched conditions. Such complexities are not evaluated here. Infiltration gallery locations are indicated in the figures for the alternatives.

## **6.1 EXPEDITED CAPTURE ALTERNATIVE**

This alternative corresponds to Scenario 7 in Table 3 of Appendix C of the SWOU FS (AFCEE 1999a). As listed in Table B6-1, this alternative consists of one extraction and reinjection well pair and five extraction wells in the CS-21 plume. The expedited capture alternative is illustrated in Figure B-15, and extraction performance is tabulated in Table B6-2. The extraction and reinjection well pair (RW-A1), located at the downgradient end of the plume, extracts contaminated water at depth and reinjects treated water at a shallower level in the same well bore. This configuration minimizes perturbations to the water table. The five extraction wells are arrayed across the middle and upgradient portions of the plume, with treated water returned to the aquifer via peripheral infiltration galleries (IG-A1 and IG-A2), which are shown in Figure B-15. The extraction and reinjection well pair pumps at 200 gpm, and the extraction wells pump at a total of 1200 gpm.

Particle tracks for the FS-29 plume, Figure B-15, show that the direction of groundwater flow is westerly (approximately S75W) and nearly uniform along the length of the plume. In contrast, the azimuth of the axis of the plume ranges from S40W near the upgradient end to S75W at the toe of the plume. Thus, groundwater flow in the model carries the upgradient portion of the plume to the extraction wells in the CS-21 Plume. As summarized in Table B6-2, 22.8 percent of the FS-29 plume is captured after 30 years. A plot of extraction versus time (not shown) indicates the extraction rate is nearly constant for the first 25 years, at approximately 4 percent per year, after which little additional mass is extracted. Performance of this alternative with respect to the CS-4, CS-20 and CS-21 plumes was presented in the SWOU FS Appendix C (AFCEE 1999a).

## **6.2 FS-29 FULL CAPTURE ALTERNATIVE**

The FS-29 full capture alternative is illustrated in Figure B-16, and extraction performance is tabulated in Table 6-2. This alternative corresponds to Scenario 10 in Table 3 of Appendix C of the SWOU FS (AFCEE 1999a). The configuration of extraction wells and infiltration galleries is identical to that of the full-capture alternative (Scenario 11 in Table 3 of Appendix C of the SWOU FS), with the addition of two extraction wells (EW-D1 and EW-D2) along the axis of the FS-29 plume near the downgradient end. These wells pump at 300 gpm each, with treated water reinjected at infiltration gallery IG-D1.

As in the expedited capture alternative, particle tracks in Figure B-16 show that groundwater flow in the model carries the upgradient portion of the plume to the extraction wells in the CS-21 Plume. The upgradient portion is completely captured. The downgradient portion is more difficult to capture. EW-D2 combines with EW-A1 in the CS-21 plume to create a fence across the plume, one quarter of the length of the plume upgradient from the toe. This fence captures all of the plume flowing through this cross-section during the early part of the modeling period. However, an animated side view showed that after approximately seven years, the plume has dived sufficiently to partially pass beneath EW-D2. At the toe of the plume, the capture

zone of EW-D1 is slightly narrower than the plume, allowing a few particles to pass downgradient laterally to the north. The model indicates 96 percent of the plume would be remediated after 28 years. However, because the average concentration for this plume is less than twice the MCL at the outset, it is likely the average influent concentration would drop to much less than the MCL after only a few years.

## 7.0 LIMITATIONS OF MODEL RESULTS

The SWOU Zoom Model, like all groundwater models, is only an approximation of reality. Although the model strives to capture the salient features of the groundwater system, many simplifications are necessary in order to reduce the complexity of the model and to interpolate various parameters from the available supporting data. Some of the shortcomings of the model become apparent as results are compared to field observations, whereas others can only be inferred indirectly. Known shortcomings follow.

- Plume trajectory south of the western arm of Coonamessett Pond curves to the west, outside the observed plume boundary. Because this part of the plume is in an area of convergent flow as it approaches the discharge zone along the Coonamessett River, the plume should not move or spread laterally.
- Insufficient vertical conductivity in the vicinity of FS-28 EW-1. Evaluation of the EW-1 pump test using the EW-1 Zoom Model (AFCEE 1998) obtained a good fit to observed drawdowns using an anisotropy ( $K_h/K_v$ ) of 3. In contrast, the SWOU Zoom Model in this area has anisotropies of 7 to 25 in the deep sands, and up to 115 in silts. Thus, vertical flows in the SWOU Zoom Model are underestimated, and the influence of discharge zones does not propagate deeply. This is apparent in the side-view particle animations, which show the head of the plume migrating along the Coonamessett River. In reality, the plume discharges to the Coonamessett bogs immediately south of FS-28 EW-1 as suggested by field observations and the initial contaminant distribution.
- Slow flow rates at depth. Particle trajectories from suspected source areas to present plume locations obtained during calibration of the 1999 Regional Model and the SWOU Zoom Model (AFCEE 1999a) suggest that flow velocities may be low by as much as a factor of two in some of the deeper parts of the aquifer. At least part of the reason for this is the comparatively high anisotropy required in order to achieve a reasonable calibration of the flow model (AFCEE 1999a). High anisotropy implies low vertical conductivity, partially isolating the deeper portions of the aquifer from the active groundwater flow system. Although FS-28



was not among the plumes used for source-area calibration, the anisotropy problems discussed above suggest that it is similarly affected.

- Predicted drawdowns are not greatly influenced by the presence of Coonamessett Pond. For example, contours indicating mounding in Alternative 6 (Figure B-12) cut across the western arm of Coonamessett Pond. The pond cells have a hydraulic conductivity of  $1 \times 10^6$  feet per day, which is thought to be sufficient to preserve a level water surface in the pond. However, the model results imply that the level of the western arm of Coonamessett Pond is several tenths of a foot higher than the rest of the pond. Because such a gradient should induce a flow of several thousand gpm in the model, it is surprising that the mounding contours do not skirt the pond instead of cutting across it. At this time, the source of this discrepancy has not been resolved.
- Differences between kriged and manually interpolated plume shells. The kriging process (AFCEE 1999a, Appendix C) includes a mask that constrains the lateral dimensions of the resulting plume, and vertical spreading is minimized by using a vertical to horizontal ratio of influence (anis2) of 0.05, the smallest value permitted by GMS (EMS-i 1999). Nevertheless, the kriged plume is somewhat thicker than the manually interpolated plume and implies low levels of contamination in some wells that have not shown any detections during sampling.
- FS-28 plume capture by Coonamessett Pond as tabulated by Spltp93 seems greater than the visual impression presented by the animations. The criterion used by Spltp93 to determine capture by Coonamessett Pond should be reviewed.
- The present shape of the plumes provides an indication of the direction of groundwater flow in each area. For the FS-29 plume, however, the plume axis suggests much greater curvature of groundwater flow paths than the model exhibits, which raises some doubt about the modeled trajectory of the upgradient portion of this plume into the CS-21- plume extraction wells.
- The FS-29 plume tends to sink with time until it begins to pass beneath the extraction wells. It seems unlikely that vertical velocities near the plumes are as great as those simulated. The plume begins to pass beneath the FS-29 plume extraction system after seven years, thus providing a good measure of the length of time that the SWOU Zoom Model can project into the future with confidence.

In addition to these issues, the particle-tracking analysis presented here does not account for fate-and-transport processes, e.g., degradation, dispersion, and retardation. Fate-and-transport analysis performed for the CS-4, CS-20, CS-21, and FS-29 plumes in the SWOU (Project Note #AFC-J23-35Q86101-P1-0082, 4/15/99) compared to particle-track analyses performed in support of the SWOU FS (AFCEE 1999a Appendix C) shows that the two approaches produce similar results in the absence of significant degradation or retardation. As discussed in that project note,

for EDB, retardation is expected to be minimal, but degradation may be significant. Under these conditions, particle-tracking analysis is conservative, predicting longer remediation times than the more rigorous fate-and-transport approach.

Overall, the concerns presented here do not compromise the usefulness of this modeling exercise at the conceptual level for the northern portion of the FS-28 plume or the FS-29 plume. The SWOU Zoom Model is not appropriate for the southern portion of the plume because of inaccuracies in the flow field there. Remedial designs examined here are meaningful within the context of the model because they are optimized to remediate the kriged plumes as they move within the modeled flow field. Actual system designs would require a more realistic flow model in which the above concerns have been addressed and corrected.

## **8.0 SUMMARY**

Alternatives 4, 5, 6, and 7 each effectively speeds capture of the northern portion of the FS-28 plume. In doing so, these alternatives reduce the time to restore the aquifer in the FS-28 plume as a whole. The configuration and performance of each alternative is summarized in Table B8-1. Alternative 6 is the most successful, capturing the largest fraction of the northern plume instead of letting it discharge to Coonamessett Pond, and reaching completion in the shortest time. This alternative employs far fewer extraction wells than Alternatives 4 or 5 (five wells versus 20 or 10, respectively), but with a similar total pumping rate. This illustrates the effectiveness and economy of a few carefully sited higher-capacity extraction wells compared to the brute-force approach of a fence of closely spaced lower-capacity wells.

Alternative 7 also uses only a small number (three) of extraction wells. Because of its more southerly location, it will take several years longer for all of the northern plume to migrate to the extraction wells. However, its more southerly location also reduces the time the existing FS-28 treatment system would need to operate.

For the FS-29 plume, the baseline scenario, the CS-21 plume expedited capture alternative, and the FS-29 full capture alternative represent a continuum of increasingly vigorous remedial action. For the baseline scenario, equivalent to long-term monitoring, the plume slowly migrates toward the ocean, with a small amount (approximately 20 percent after 30 years) of discharge to bodies of surface water along the way. Although particle tracking shows remnants of the plume persisting for more than 100 years, in reality dispersion and degradation will most likely reduce the plume to less than the MCL long before then. The expedited-capture alternative for the CS-21 plume shows how another 23 percent of the FS-29 plume might be intercepted by these remedial actions. The FS-29 full capture alternative provides an indication of the level of effort required to achieve nearly complete capture. Although the simulation shows that very little of the plume escapes at a pumping rate of 600 gpm, the merits of such an action must be weighed against expected costs and reductions in risk.

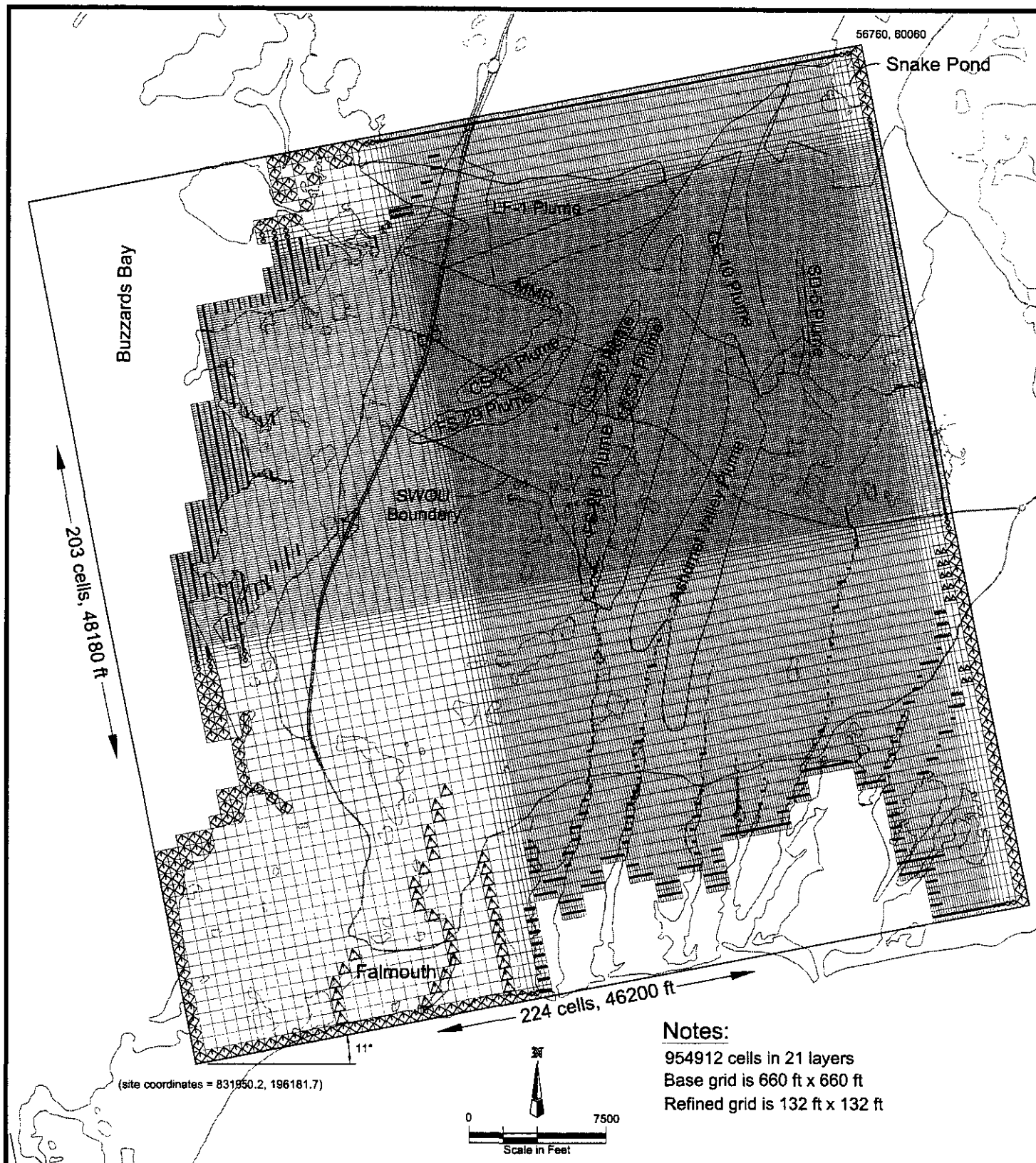
## 9.0 REFERENCES

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- \_\_\_\_\_. 1999b (May). *Final Southwest Operable Unit (SWOU) Remedial Investigation*. Prepared by Jacobs Engineering Group Inc. for AFCEE/MMR Installation Restoration Program, Otis ANGB, MA.
- \_\_\_\_\_. 1998 (March). *FS-28 Treatment System, Extraction Well-1 (EW-1) Evaluation Report Time Critical Response Action*. Prepared by Jacobs Engineering Group Inc. for AFCEE/MMR Installation Restoration Program, Otis ANGB, MA.
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- HydroGeoLogic Inc. 1996. *MODFLOW/SURFACT v. 1.2*. Herndon, VA.

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## **APPENDIX B**

### **Figures**



### Legend

- ◇ Constant-head cell
- △ Drain cell

Columns			
# of cells	Cell size (ft)	Width (ft)	
28	660	18480	(x=0)
2	330	660	
3	220	660	
185	132	24420	
3	220	660	
2	330	660	
1	660	660	
224		46200	

Rows			
# of cells	Cell size (ft)	Height (ft)	
32	660	21120	(y=0)
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3	220	660	
155	132	20460	
3	220	660	
2	330	660	
6	660	3960	
203		48180	



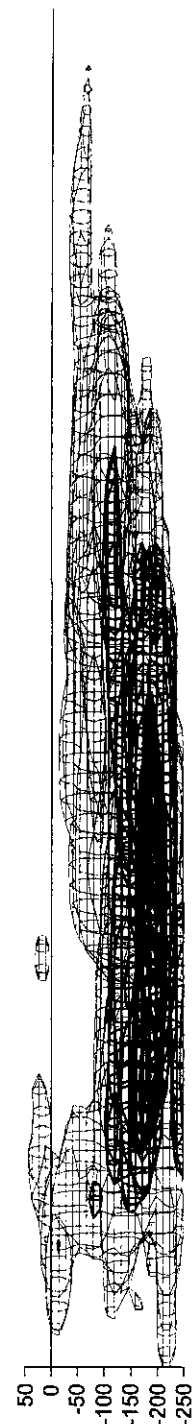
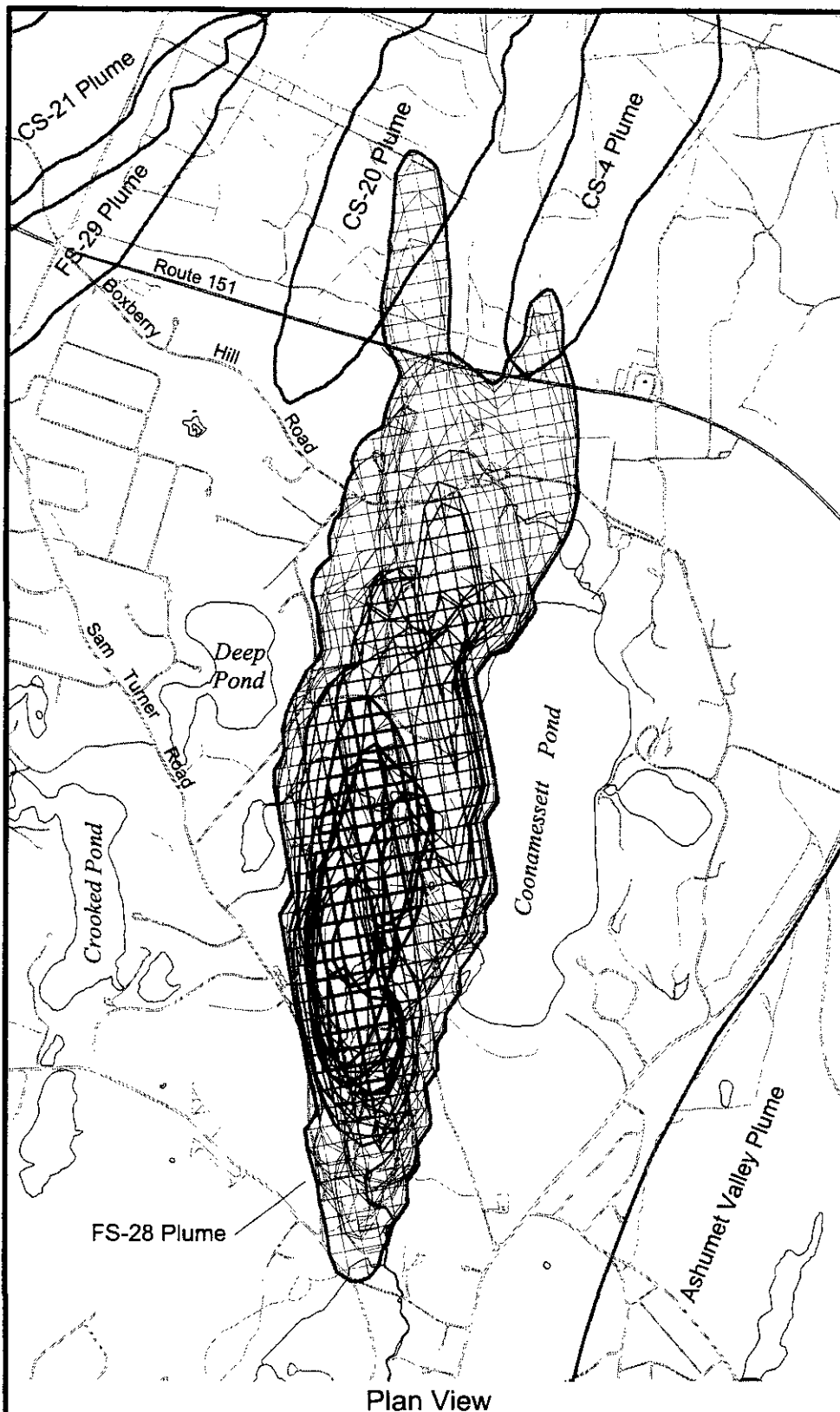
JACOBS ENGINEERING

### Boundary and Grid for the SWOU Zoom Model

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Cape Cod, Massachusetts

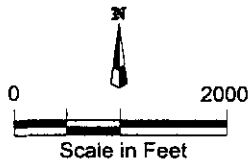
6/28/99 la SwouMdlLayout.dwg

Figure B-1



### Legend

Concentrations are for EDB only  
 Plume shell outline drawn at 0.004  $\mu\text{g/L}$   
 Isosurfaces contoured at .002, 0.5, and 2.5  $\mu\text{g/L}$   
 Total EDB = 11.72 kg  
 Average EDB = 0.71  $\mu\text{g/L}$   
 Maximum concentration = 16.0  $\mu\text{g/L}$



JACOBS ENGINEERING

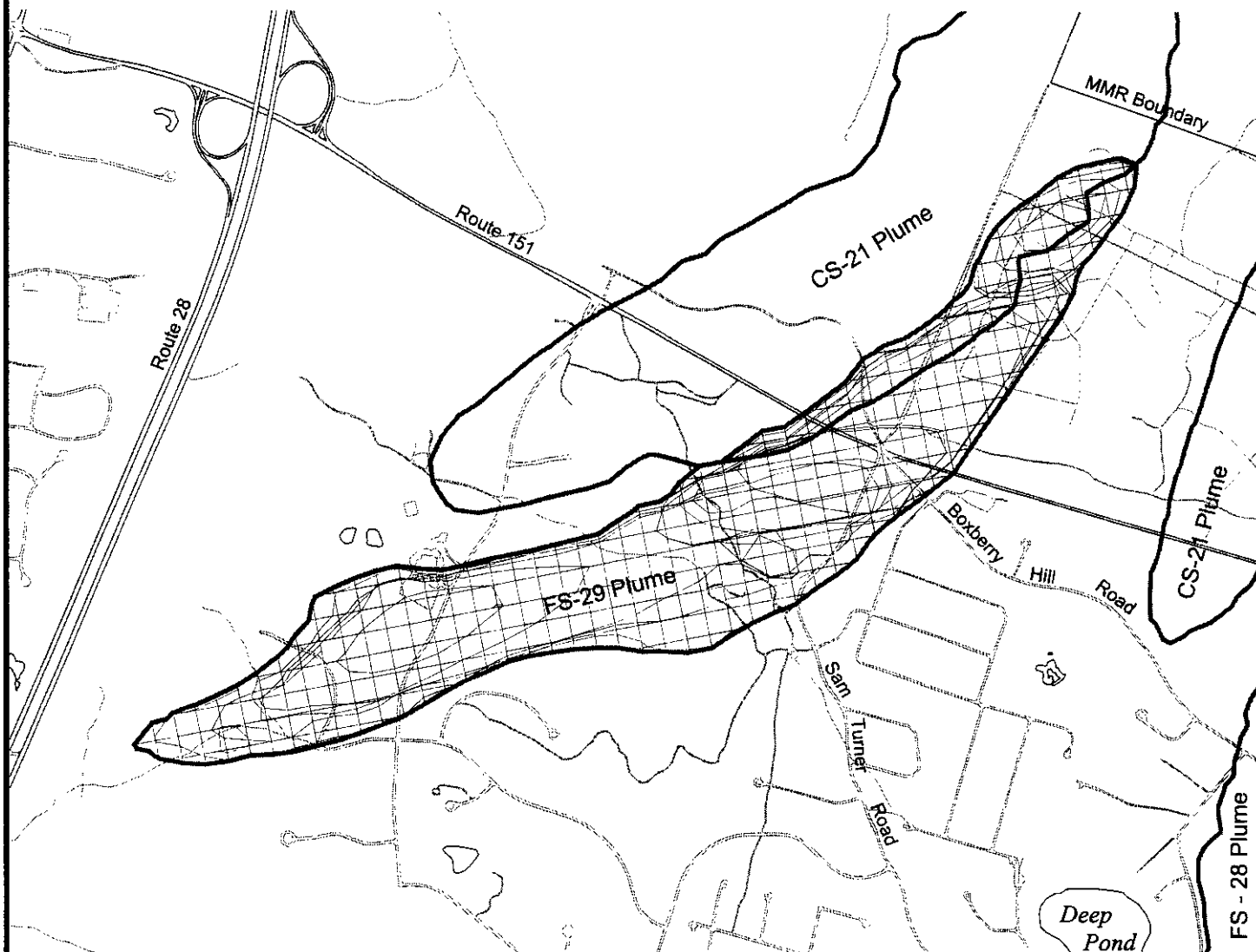
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 Cape Cod, Massachusetts

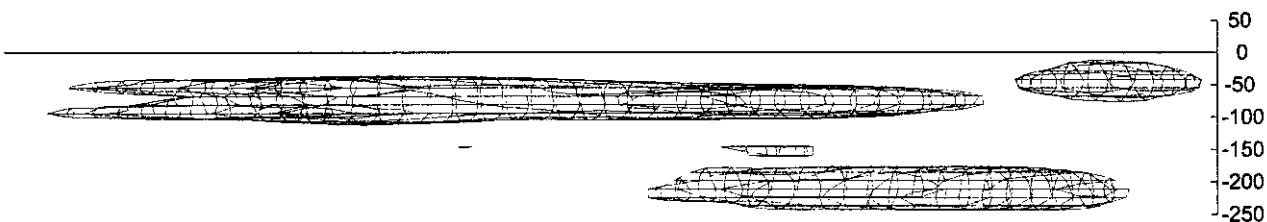
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Figure B-2

# Plan View



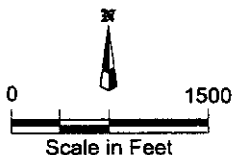
## View to North



Vertical exaggaration = 5x

### Legend

Concentrations are for EDB only  
 Plume shell outline drawn at 0.004  $\mu\text{g/L}$   
 Isosurface contoured at 0.02  $\mu\text{g/L}$   
 Total EDB = 0.16 kg  
 Average EDB = 0.037  $\mu\text{g/L}$   
 Maximum concentration = 0.090  $\mu\text{g/L}$



JACOBS ENGINEERING

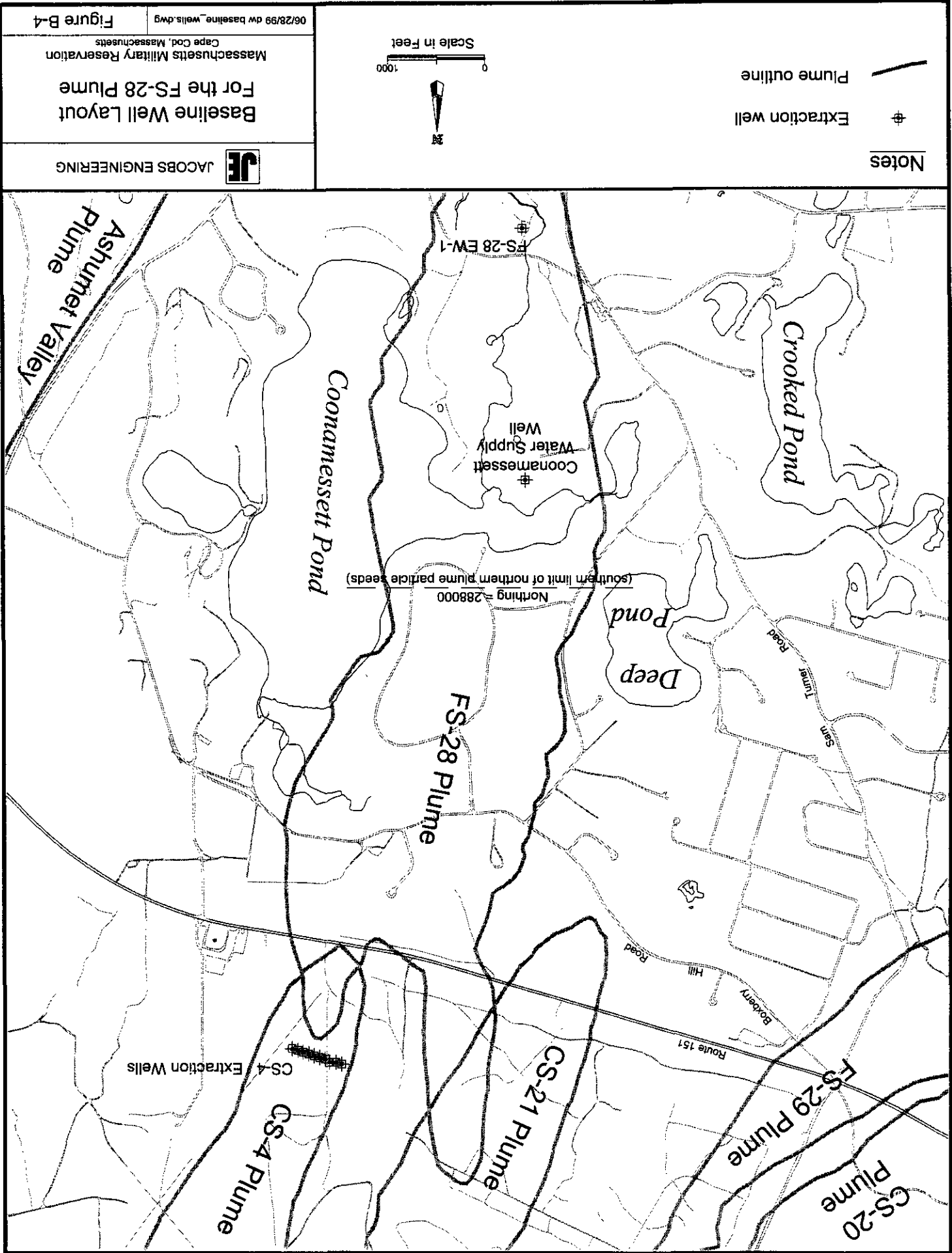
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Massachusetts Military Reservation  
Cape Cod, Massachusetts

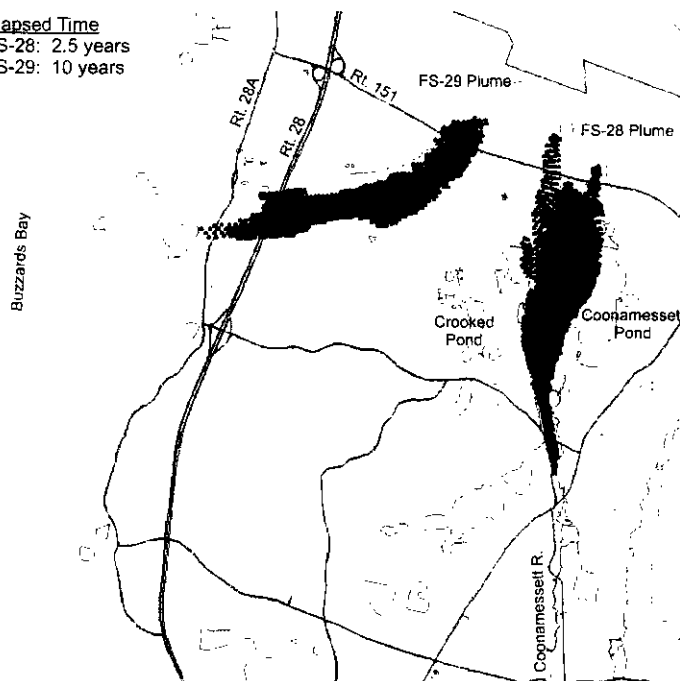
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Figure B-3

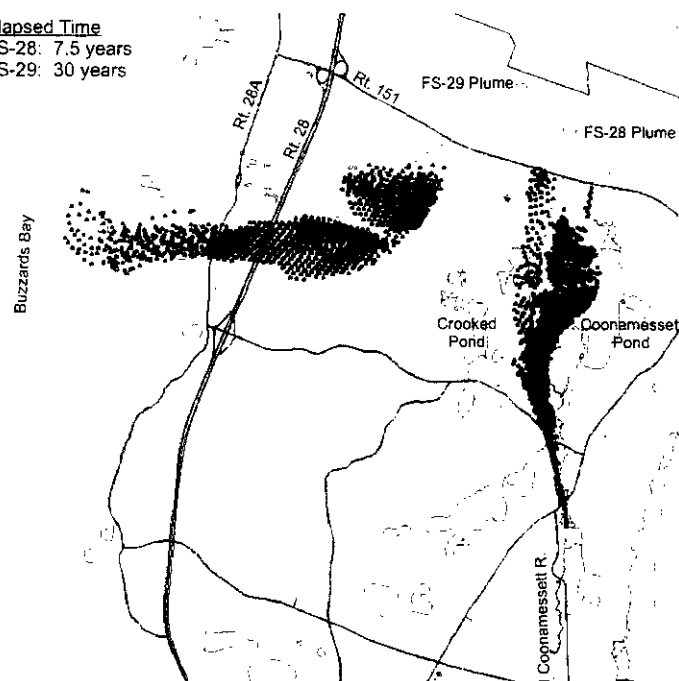




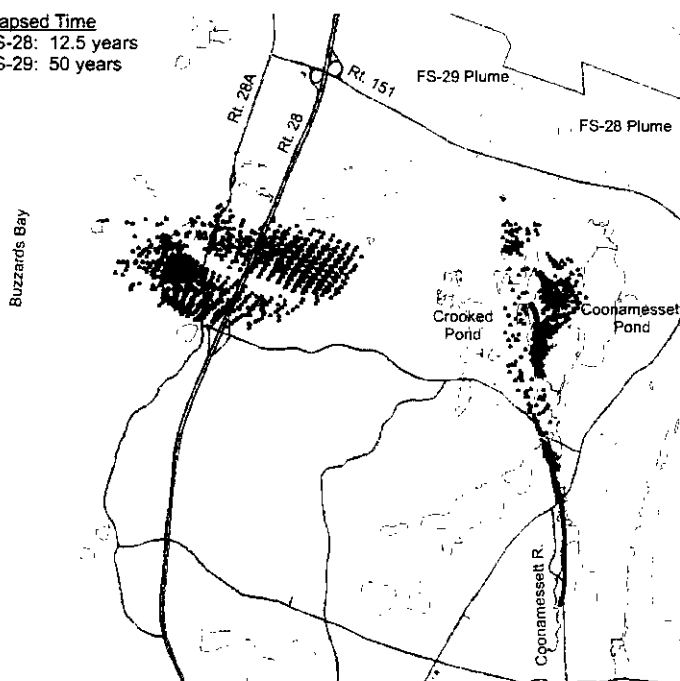
Elapsed Time  
 FS-28: 2.5 years  
 FS-29: 10 years



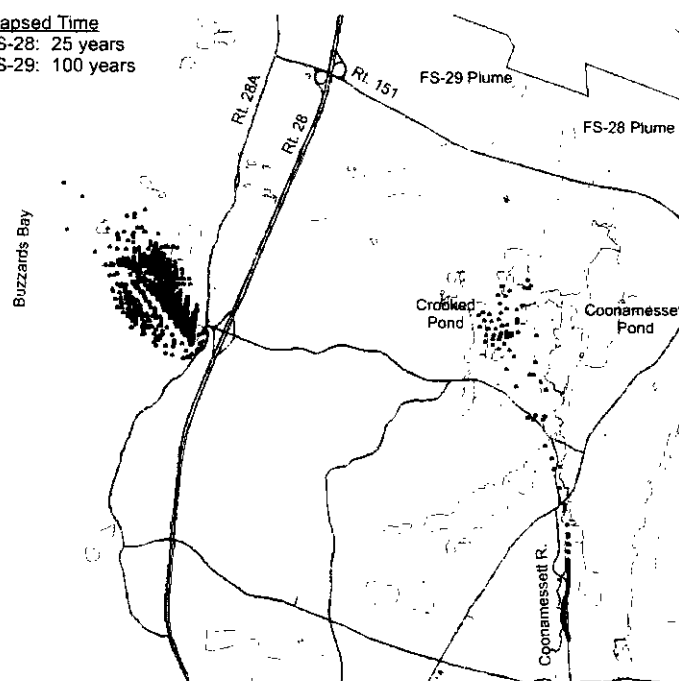
Elapsed Time  
 FS-28: 7.5 years  
 FS-29: 30 years



Elapsed Time  
 FS-28: 12.5 years  
 FS-29: 50 years

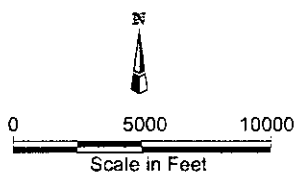


Elapsed Time  
 FS-28: 25 years  
 FS-29: 100 years



#### Notes

1. Plume outlines drawn at the MCL for EDB (0.02  $\mu\text{g/L}$ ).
2. Elapsed time is corrected for unrealistically slow advection in the vicinity of FS-28, whereas model time is used for FS-29.



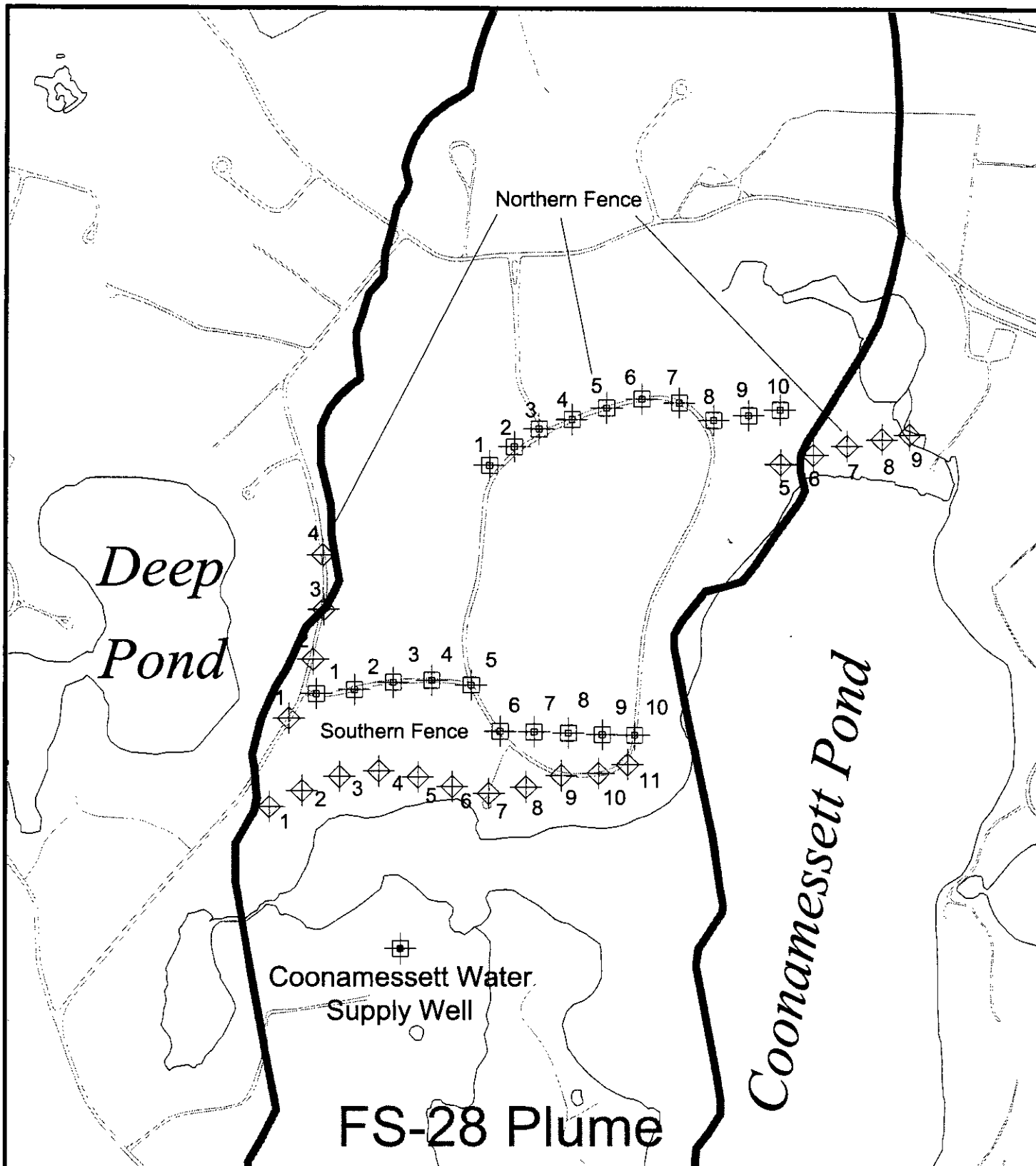
JACOBS ENGINEERING

#### Baseline Plume Migration for the FS-28 and FS-29 Plumes




Massachusetts Military Reservation  
 Cape Cod, Massachusetts

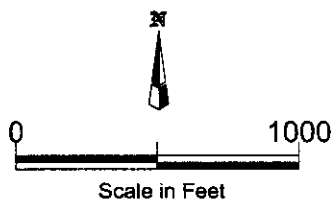
11/23/99 dw Baseline.cdr

Figure B-5



#### Notes

-  Extraction well
-  Injection well
-  Plume outline



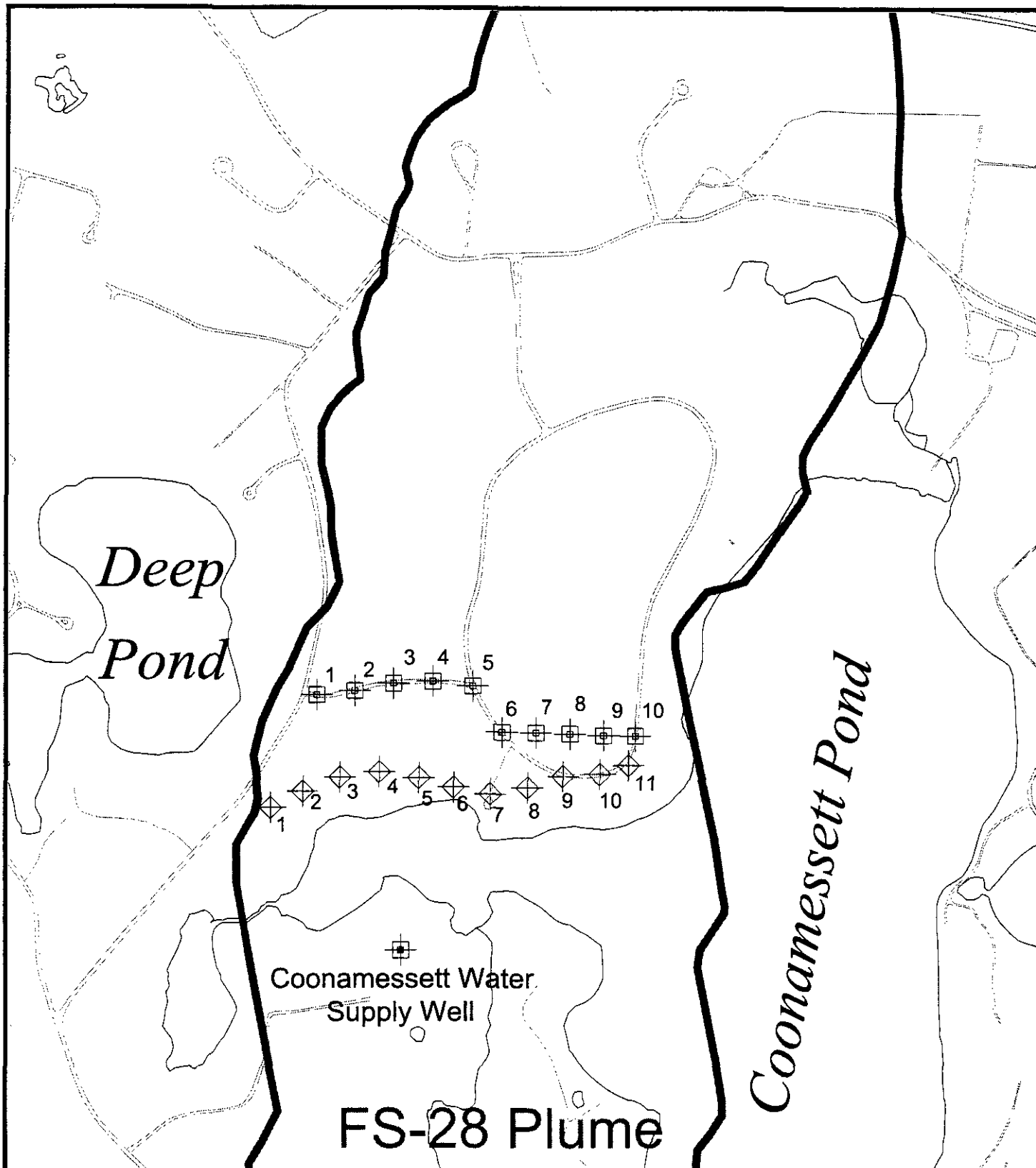
JACOBS ENGINEERING

#### Well Layout for FS-28 Alternative 4




Massachusetts Military Reservation  
Cape Cod, Massachusetts

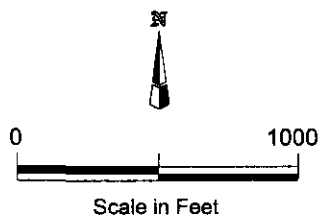
06/28/99 dw All4R17\_wells.dwg

Figure B-6



#### Notes

-  Extraction well
-  Injection well
-  Plume outline



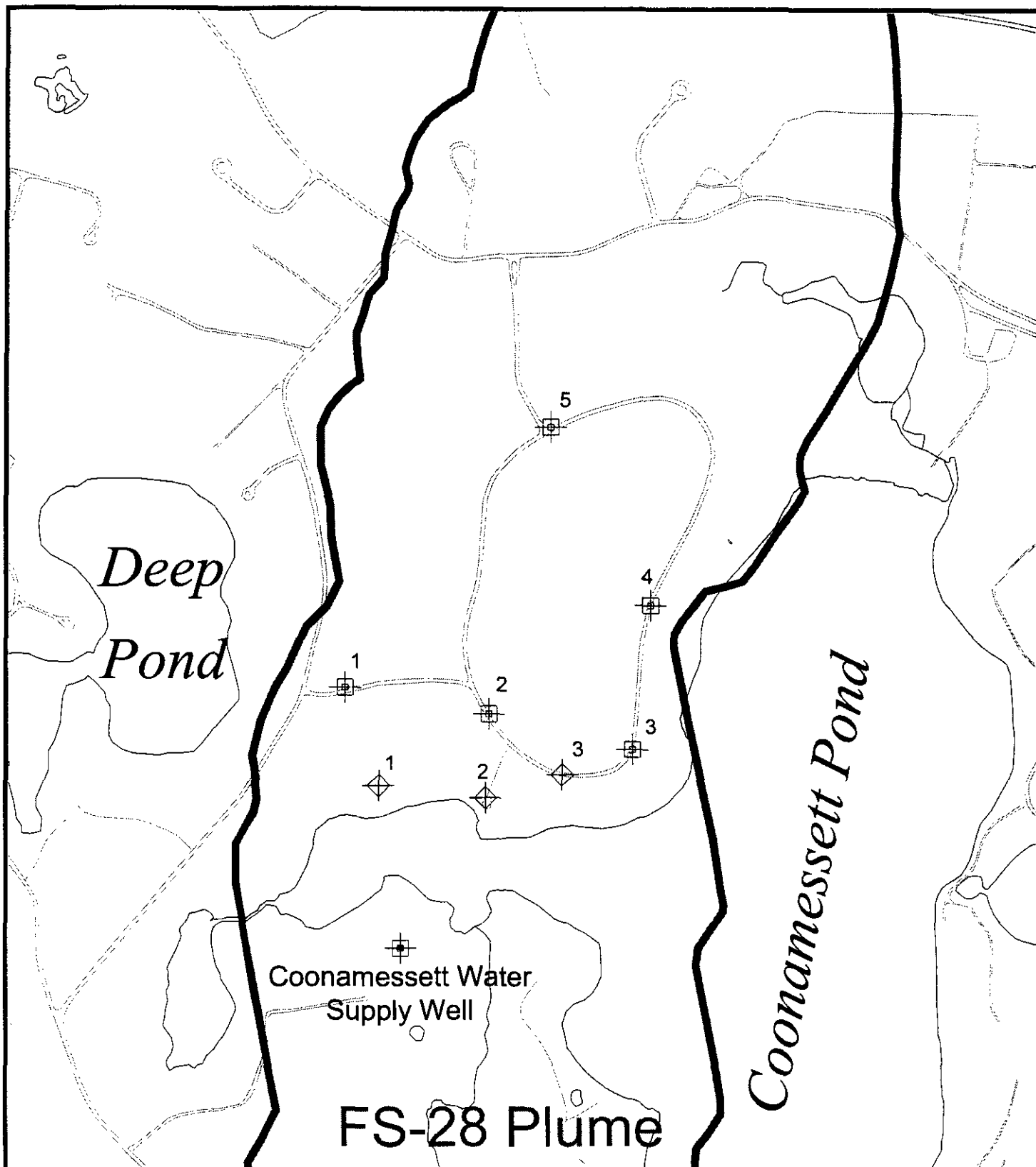
JACOBS ENGINEERING

#### Well Layout for FS-28 Alternative 5




Massachusetts Military Reservation  
Cape Cod, Massachusetts

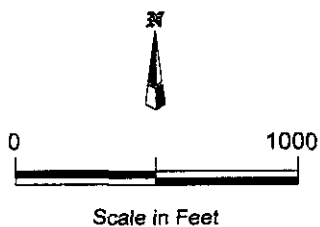
5/8/99 dw Alt5R20\_wells.dwg

Figure B-7



#### Notes

-  Extraction well
-  Injection well
-  Plume outline



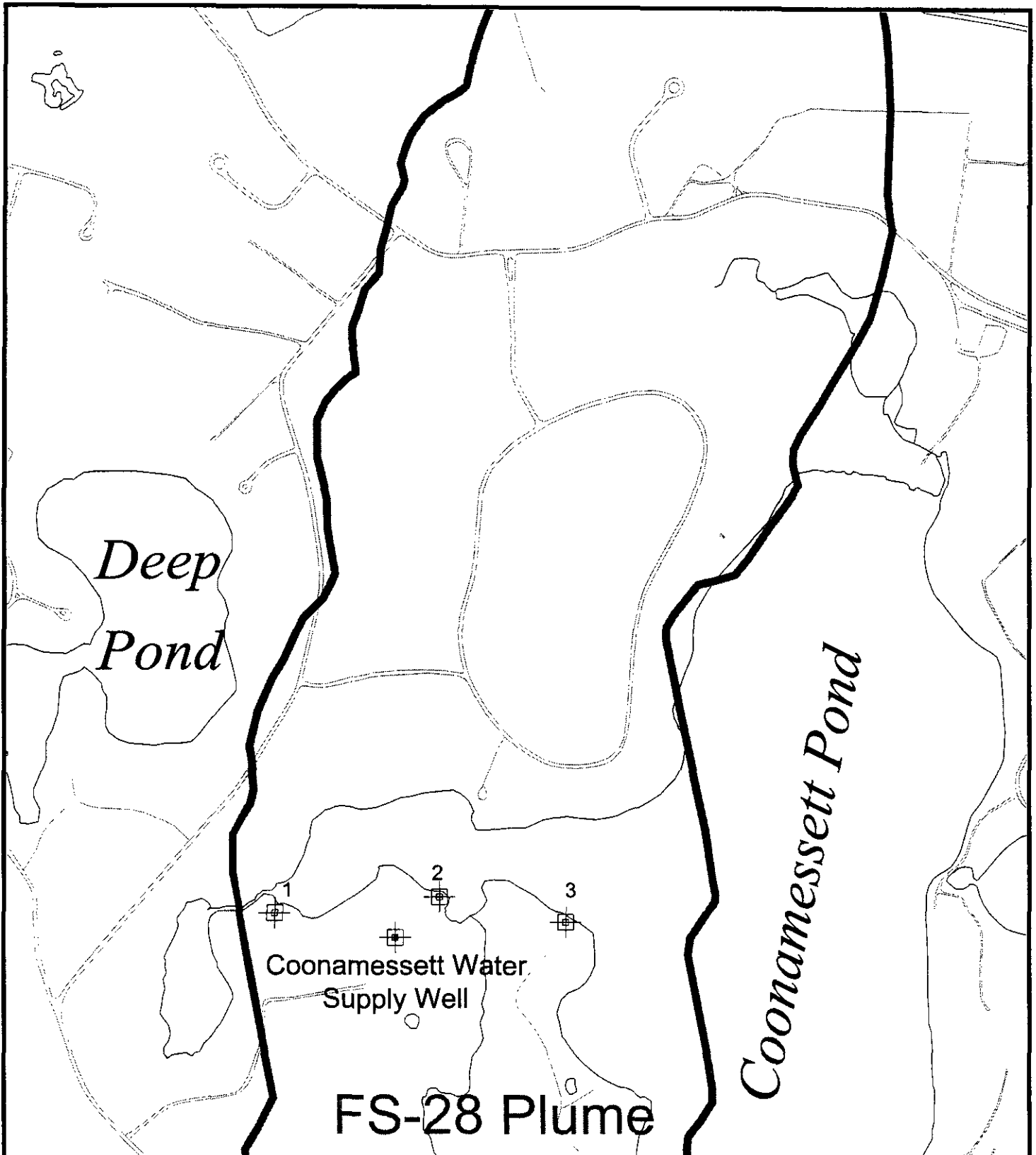
JACOBS ENGINEERING

#### Well Layout for FS-28 Alternative 6



Massachusetts Military Reservation  
Cape Cod, Massachusetts

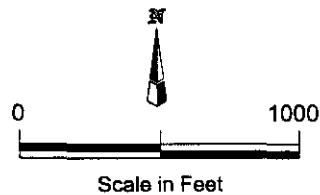
5/8/99 dw Alt6R26\_wells.dwg

Figure B-8



Notes

-  Extraction well
-  Plume outline



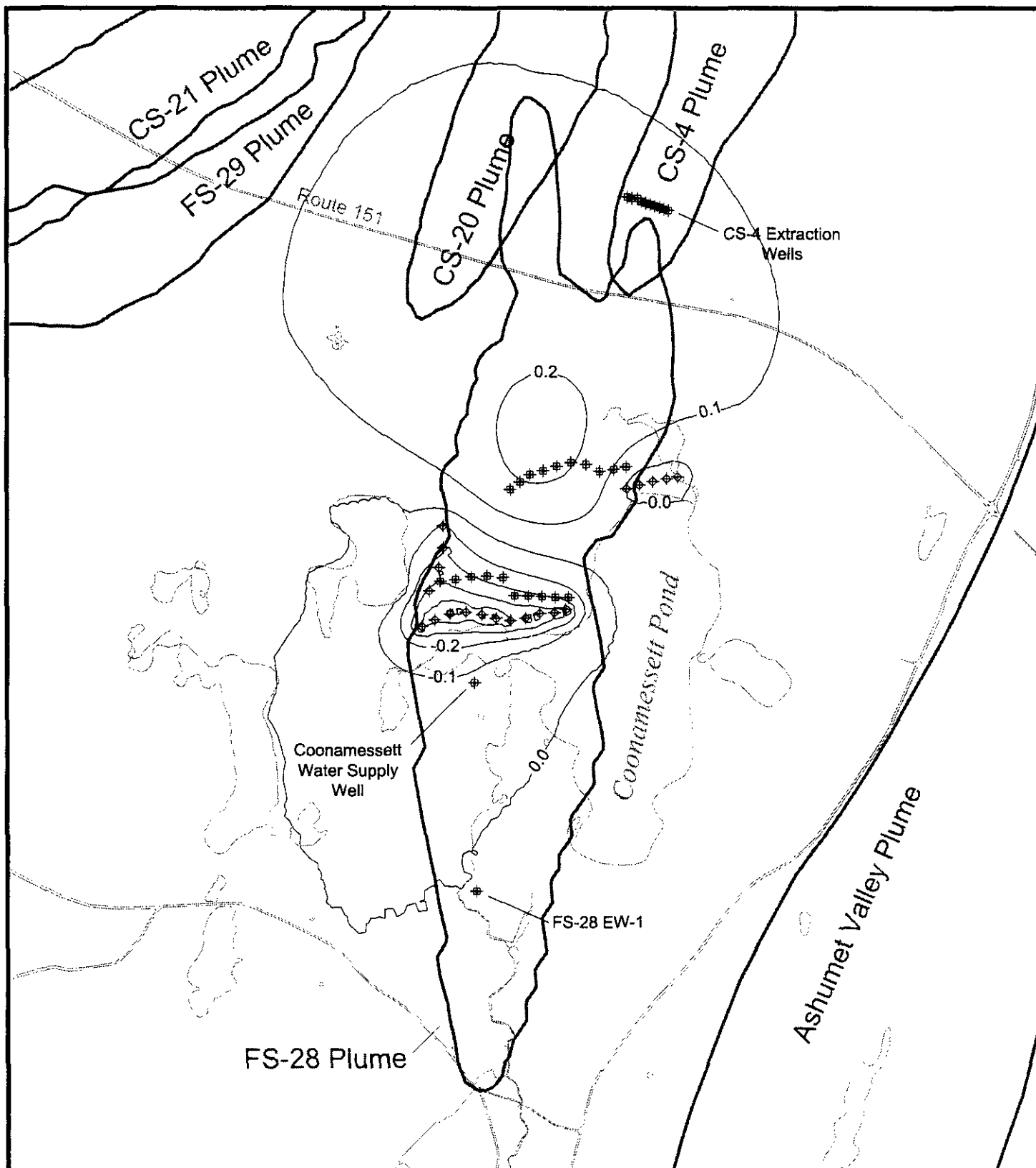
JACOBS ENGINEERING

Well Layout for FS-28  
Alternative 7

Massachusetts Military Reservation  
Cape Cod, Massachusetts

5/8/99 dw Alt7R31\_wells.dwg

Figure B-9



### Notes

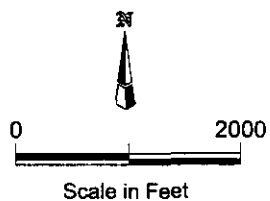
⊕ Extraction well      ⊕ Injection well

Contour interval = 0.1 ft

Positive values indicate drawdown

Negative values indicate mounding

Drawdown is in addition to that due to existing wells



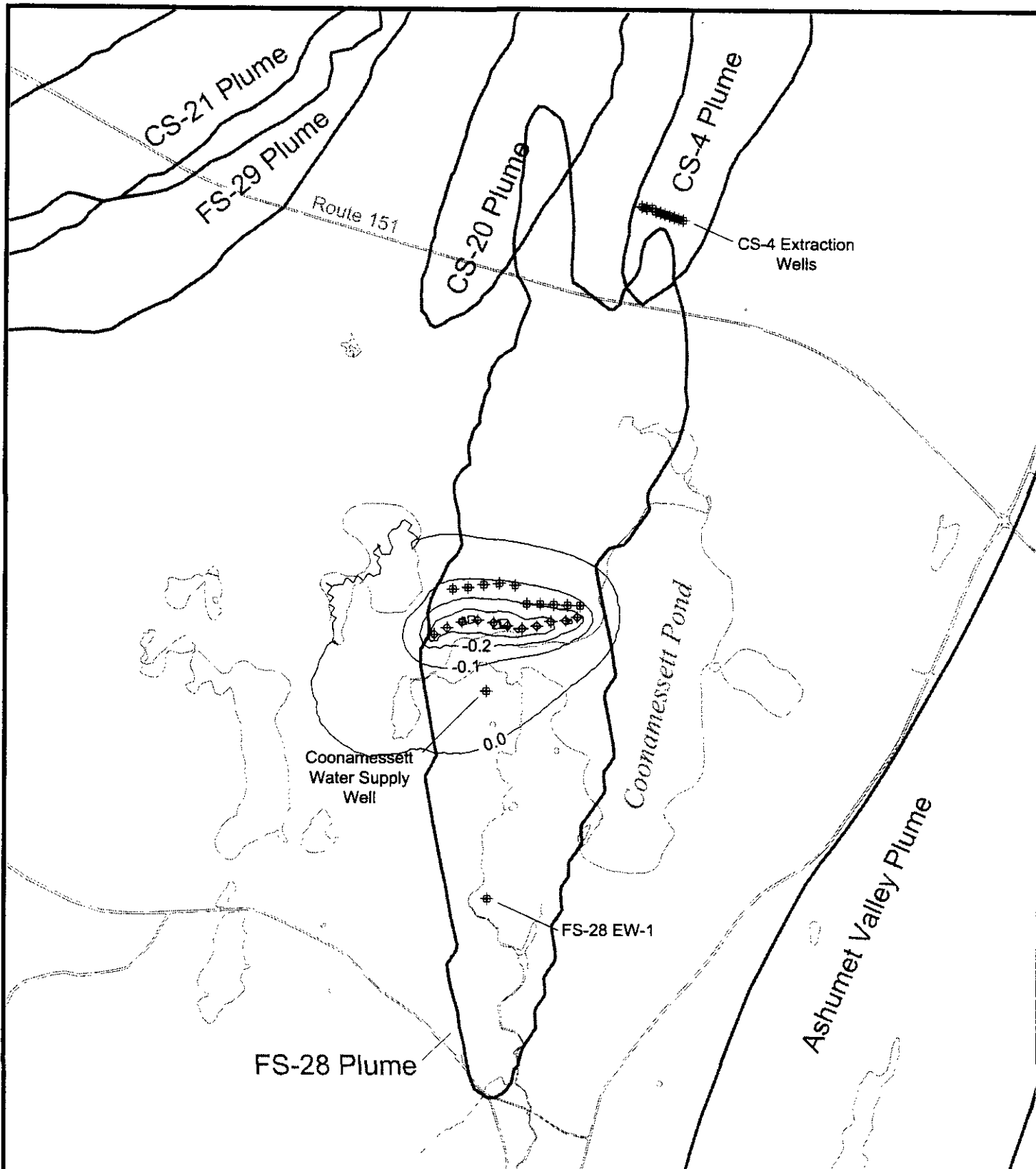
JACOBS ENGINEERING

### Water Table Drawdown for FS-28 Alternative 4

Massachusetts Military Reservation  
Cape Cod, Massachusetts

06/28/99 dw A14R17\_ddn.dwg

Figure B-10



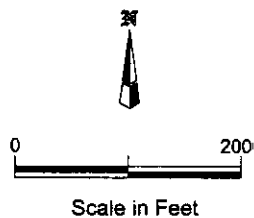
#### Notes

- ⊕ Extraction well
- ⊕ Injection well

Contour interval = 0.1 ft

Negative values indicate mounding

Drawdown is in addition to that due to existing wells



JACOBS ENGINEERING

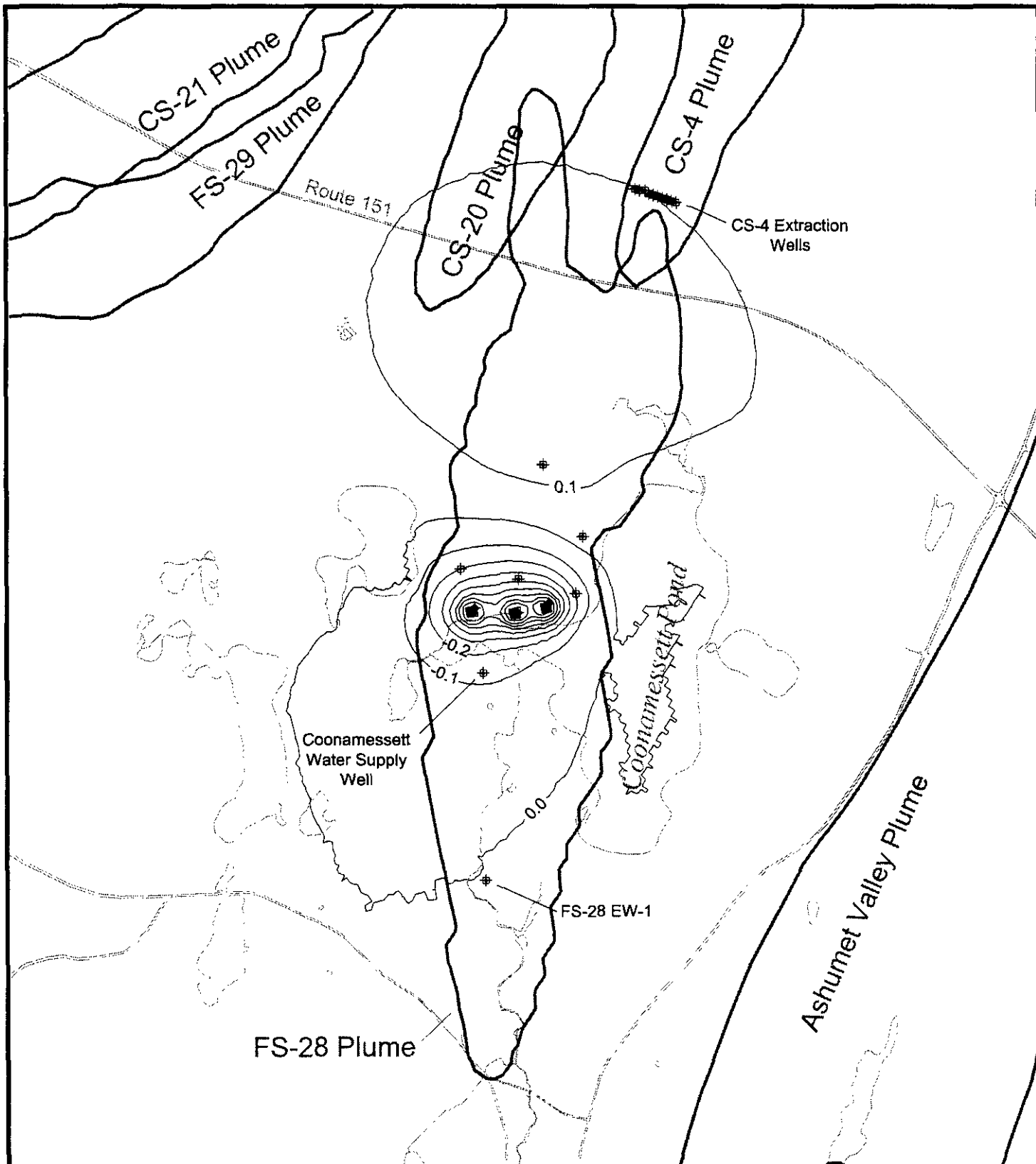
#### Water Table Drawdown for FS-28 Alternative 5

Massachusetts Military Reservation  
Cape Cod, Massachusetts

06/28/99 dw Alt5R20\_dcn.dwg

Figure B-11





### Notes

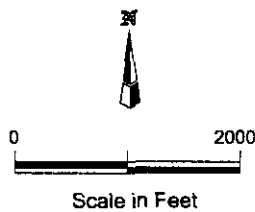
⊕ Extraction well    ⊕ Injection well

Contour interval = 0.1 ft

Positive values indicate drawdown

Negative values indicate mounding

Drawdown is in addition to that due to existing wells



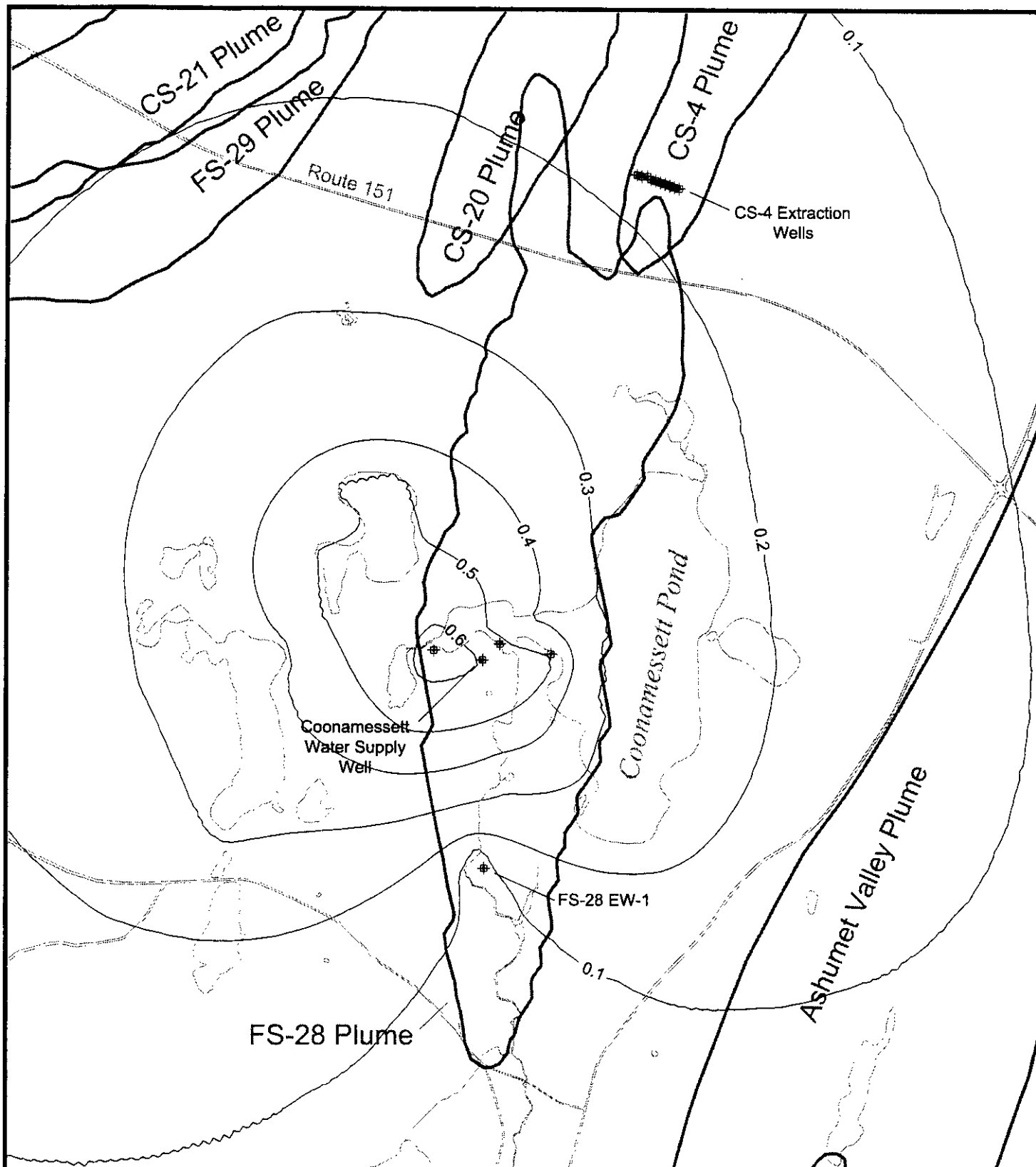
JACOBS ENGINEERING

### Water Table Drawdown for FS-28 Alternative 6

Massachusetts Military Reservation  
Cape Cod, Massachusetts

06/28/99 dw Alt6R26\_0dn.dwg

Figure B-12



### Notes

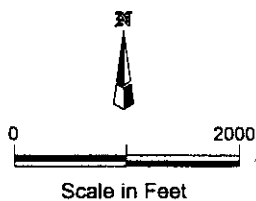
☒ Extraction well

Contour interval = 0.1 ft

Positive values indicate drawdown

Negative values indicate mounding

Drawdown is in addition to that due to existing wells



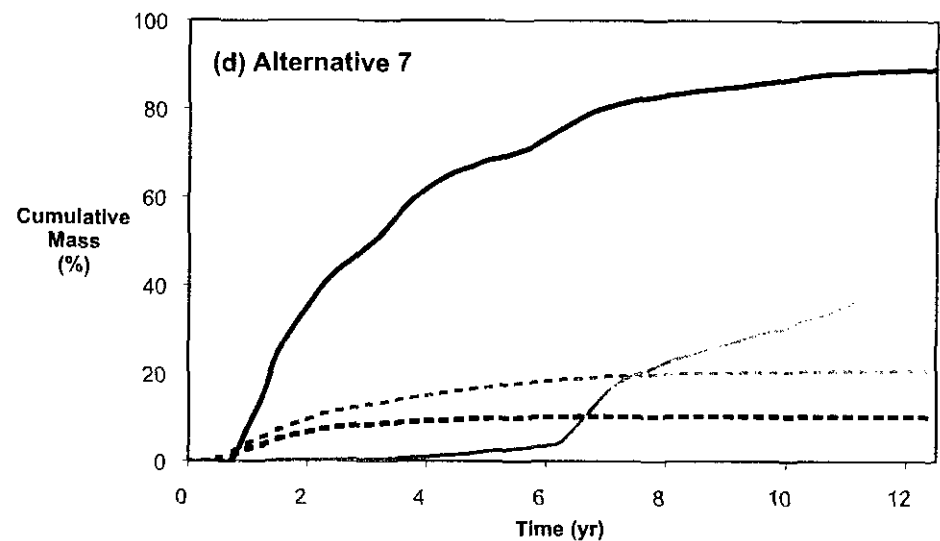
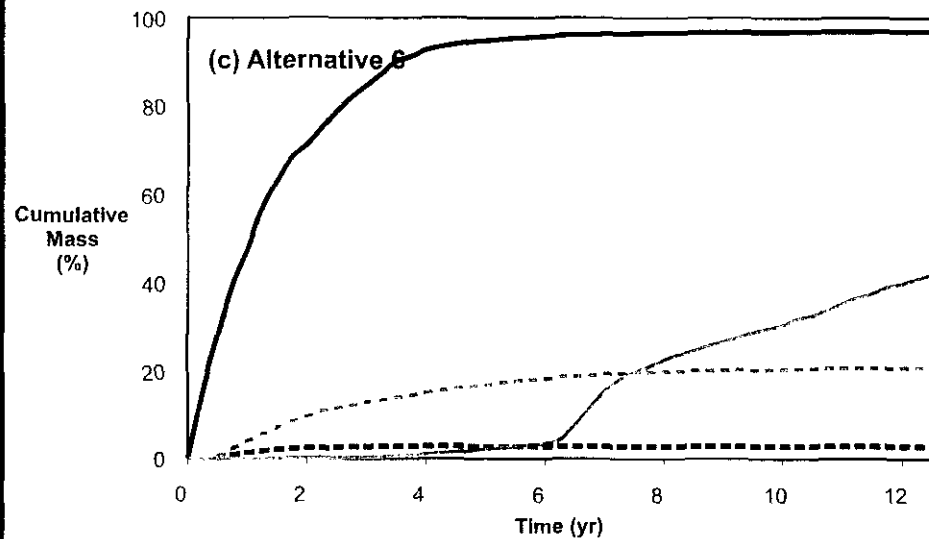
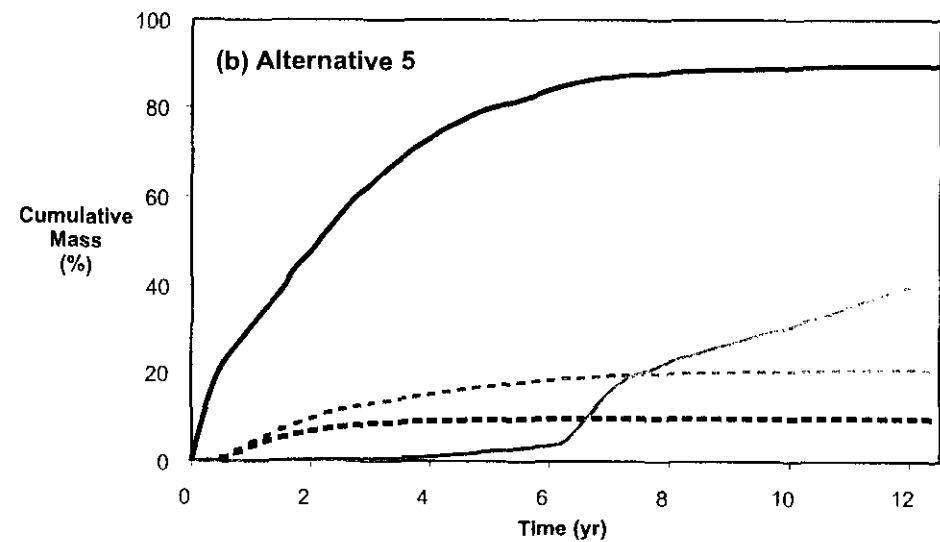
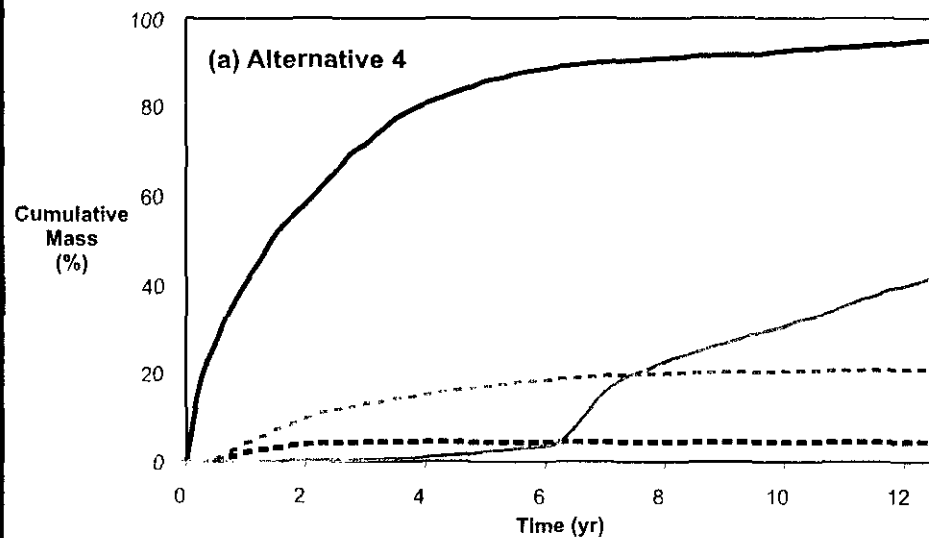
JACOBS ENGINEERING

### Water Table Drawdown for FS-28 Alternative 7

Massachusetts Military Reservation  
Cape Cod, Massachusetts

06/28/99 dw A117R31\_ddn.dwg

Figure B-13



### Legend

- Mass removal by all extraction wells
- ..... Mass discharge to Coonamessett Pond
- Baseline-scenario mass removal by extraction wells
- ..... Baseline-scenario mass discharge to Coonamessett Pond

Note: Mass removal is calculated using only the northern part of the FS-28 plume

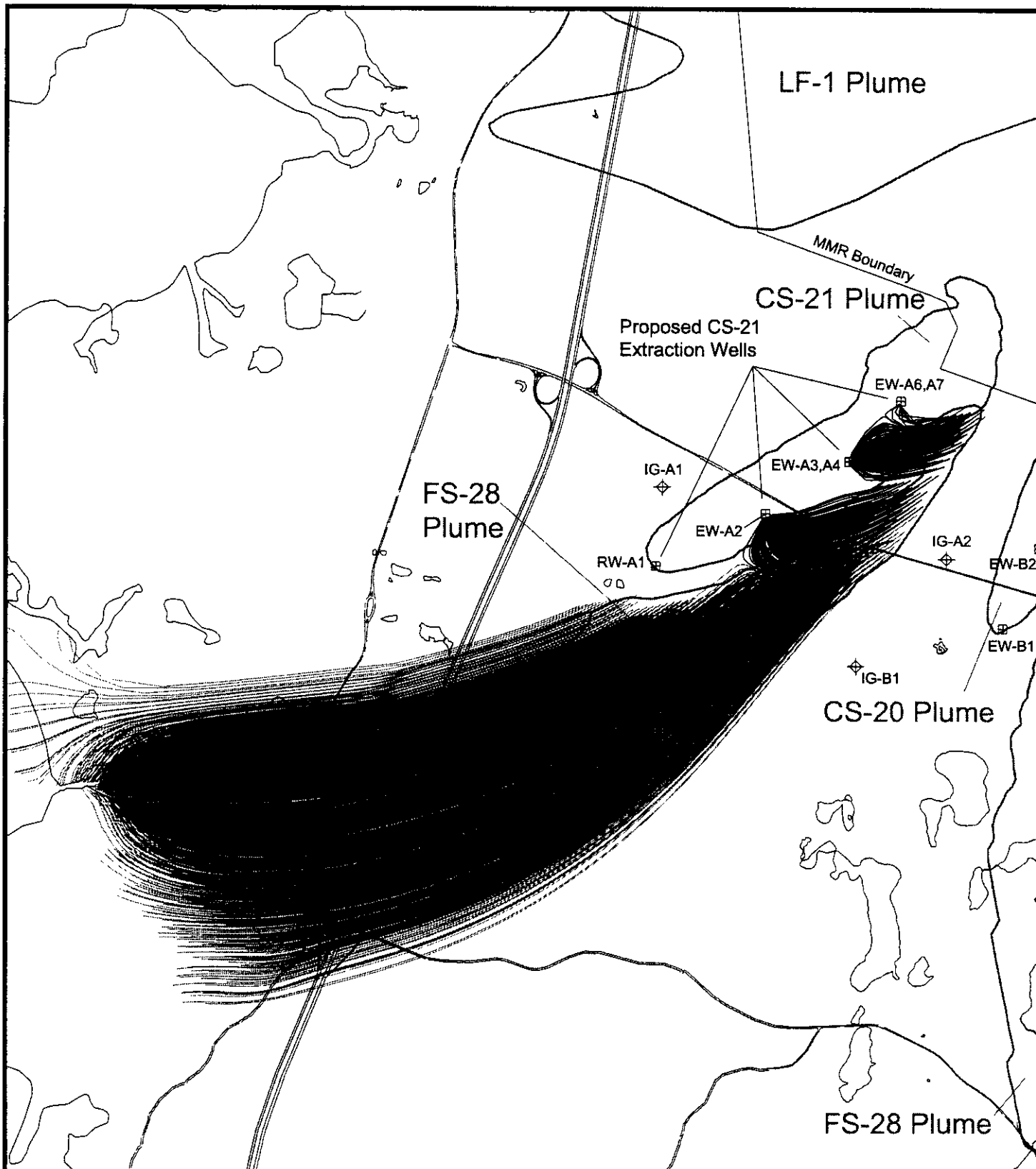


### Mass Removal versus Corrected Time for All FS-28 Alternatives

Massachusetts Military Reservation  
Cape Cod, Massachusetts

11/22/99 dw MassRemove.cdr

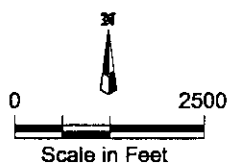
Figure B-14



### Legend

Particles tracked for 30 years  
 Plume outlines drawn at MCLs  
 Particles seeded for concentrations  $> 0.02 \mu\text{g/L}$   
 Black tracks are captured by extraction wells  
 Gray tracks remain in groundwater

■ Extraction well  
 ◆ Infiltration gallery



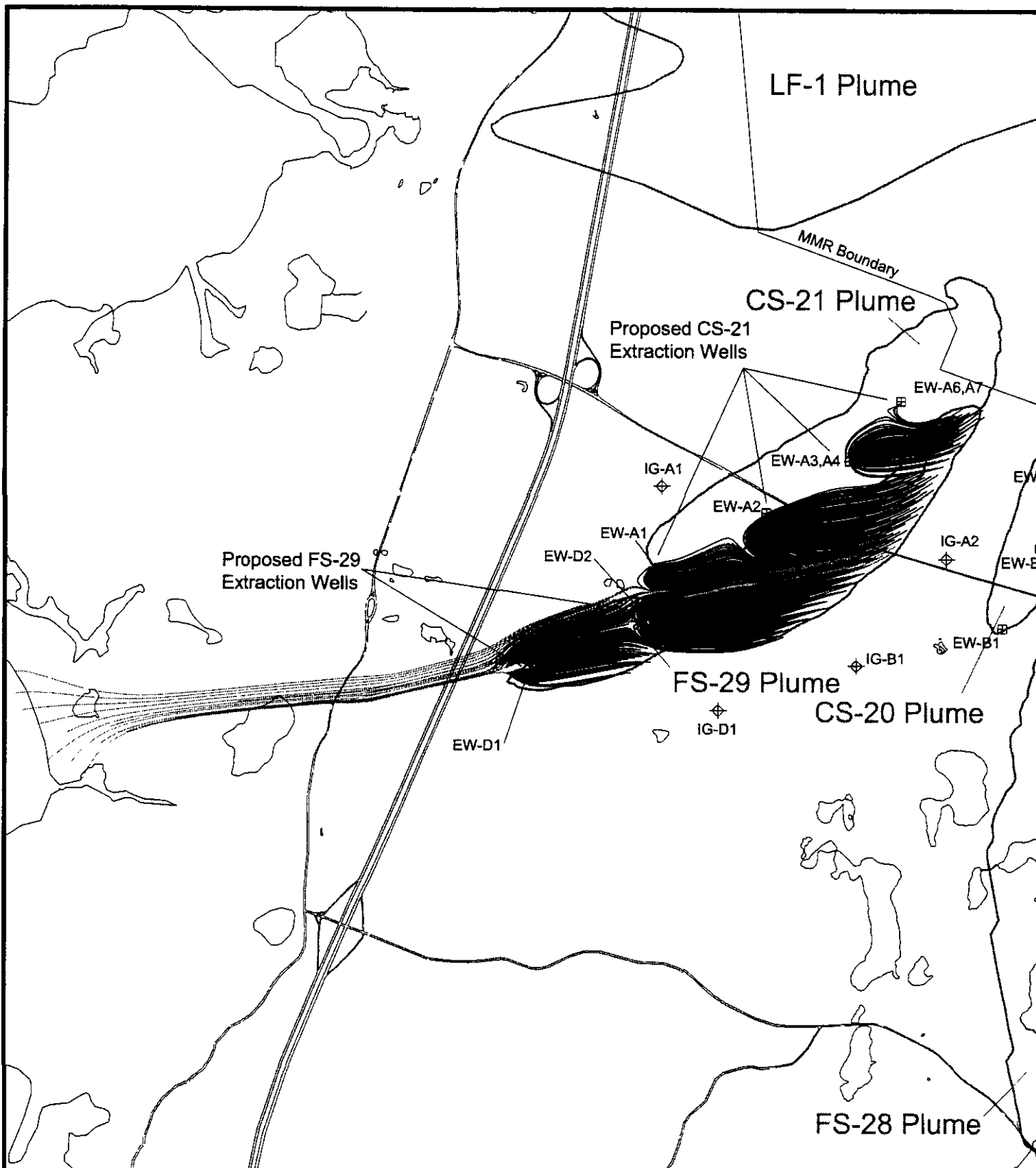
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### FS-29 Particle Tracks Under the CS-21 Plume Expedited Capture Alternative

Massachusetts Military Reservation  
Cape Cod, Massachusetts



06/28/99 dw TracksFS29\_Exp.dwg

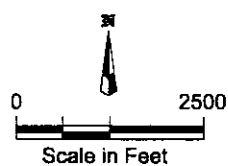
Figure B-15



### Legend

Particles tracked for 30 years  
 Plume outlines drawn at MCLs  
 Particles seeded for concentrations  $> 0.02 \mu\text{g/L}$   
 Black tracks are captured by extraction wells  
 Gray tracks remain in groundwater

 Extraction well  
 Infiltration gallery



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### FS-29 Particle Tracks Under the FS-29 Full Capture Alternative

Massachusetts Military Reservation  
 Cape Cod, Massachusetts

06/28/99 dw TracksFS29\_Full.dwg

Figure B-16

## **APPENDIX B**

### **Tables**

**Table B3-1**  
**EDB Masses for the FS-28 and FS-29 Plumes**

Plume	EDB Mass (kg)	# of Particles	Groundwater Vol. (ft <sup>3</sup> )	Average Concentration (µg/L)
FS-28	11.72	7527	5.71E08	0.71
FS-29	0.16	1997	1.51E08	0.037
Total	11.89	9524	7.22E08	0.57

kg = kilogram

ft<sup>3</sup> = cubic feet

µg/L = micrograms per liter

**Table B4-1  
Well Layout for the Baseline Scenario**

Location	Easting (ft)	Northing (ft)	Screen		Length (ft)	Pumping (gpm)
			Top (ft msl)	Bottom (ft msl)		
Coonamessett Well	843804.5	257989.2	-20.0	-40.0	20.0	-208.4
	847043.9	258618.8	20.0	0.0	20.0	-97.3
	846144.2	259788.7	-20.0	-40.0	20.0	-104.2
	866533.3	248287.8	20.0	0.0	20.0	-118.1
	854331.4	241881.9	0.0	-20.0	20.0	-138.9
	864571.4	244544.7	0.0	-20.0	20.0	-138.9
	844757.4	242710.3	-20.0	-40.0	20.0	-180.6
	844883.3	242062.4	-20.0	-40.0	20.0	-291.8
	841876.1	212566.7	0.0	-20.0	20.0	-1500.6
	853214.7	226873.0	0.0	-20.0	20.0	-402.9
	864299.9	218270.1	-20.0	-40.0	20.0	-521.2
	882133.8	212996.1	-40.0	-60.0	20.0	-27.8
	879794.2	211196.6	-40.0	-60.0	20.0	-298.7
	895291.6	252533.1	20.0	0.0	20.0	-296.4
	890269.4	233403.4	0.0	-20.0	20.0	-76.4
	889873.4	231981.7	0.0	-20.0	20.0	-62.5
	889747.5	232629.6	-20.0	-40.0	20.0	-69.5
	890503.1	228742.3	0.0	-20.0	20.0	-55.6
	894444.9	239593.8	0.0	-20.0	20.0	-377.4
	893023.3	239989.9	0.0	-20.0	20.0	-206.1
	881596.7	257267.0	0.0	-40.0	40.0	-319.5
	881165.8	273319.7	-20.0	-40.0	20.0	-416.8
	863746.0	283380.7	-60.0	-80.0	20.0	-14.1
	864393.9	283506.6	-60.0	-80.0	20.0	-14.1
HW-1	846256.0	247774.0	-20.0	-30.0	10.0	-26.2
HW-2	846624.0	248790.0	-20.0	-30.0	10.0	-26.2
HW-3	853349.0	223556.0	-20.0	-30.0	10.0	-4.5
HW-4	853740.0	222548.0	-20.0	-30.0	10.0	-2.8
HW-5	859153.0	214003.0	-20.0	-30.0	10.0	-5.3
HW-6	859148.0	214509.0	-20.0	-30.0	10.0	-5.3
HW-7	859908.0	214518.0	-20.0	-30.0	10.0	-5.3
HW-8	859902.0	215024.0	-20.0	-30.0	10.0	-5.3
Mares Pond Well	846339.8	216770.1	0.0	-20.0	20.0	-135.2
(CS4)EW0004	855640.5	232812.5	-27.4	-42.4	15.0	-20
(CS4)EW0005	855582.8	232829.9	-27.0	-42.0	15.0	-20
(CS4)EW0006	855526.6	232848.9	-26.8	-41.8	15.0	-20
(CS4)EW0007	855468.5	232867.5	-26.9	-41.9	15.0	-20
(CS4)EW0008	855412.0	232886.5	-27.4	-42.4	15.0	-20
(CS4)EW0009	855355.2	232904.9	-27.8	-42.8	15.0	-20
(CS4)EW0010	855298.4	232923.3	-27.9	-42.9	15.0	-20
(CS4)EW0011	855251.9	232960.1	-28.0	-43.0	15.0	-20
(CS4)EW0012	855184.0	232960.9	-28.0	-43.0	15.0	-20
(CS4)EW0013	855126.6	232979.1	-27.7	-42.7	15.0	-20
(FS28)EW1	853232.7	224250.1	-107.7	-168.7	61.0	-600

ft = feet

msl = mean sea level

gpm = gallons per minute



**Table B4-2**  
**Fraction of Contaminant Remaining in Groundwater as a**  
**Function of Time for Baseline Conditions**

Plume	Mass (kg)	Fraction Remaining in Groundwater (percent)			
		Time (corrected)			
FS-28	11.72	2.5 yr	7.5 yr	12.5 yr	25.0 yr
		50%	30%	26%	15%
FS-29	0.162	Time (modeled)			
		10 yr	30 yr	50 yr	100 yr
		94%	79%	55%	28%

kg = kilogram

yr = year

Note: Contaminant degradation is assumed to be zero.

**Table B5-1**  
**Well Layout of Alternative 4 for the FS-28 Plume**

Well ID	Easting (ft)	Northing (ft)	Screen Top (ft msl)	Screen Bottom (ft msl)	Length (ft)	Pumping (gpm)	Total Pumping (gpm)
<i>Southern Fence Extraction Wells</i>							-292.3
EW1	852794.2	228158.5	-85	-195	110	-28.2	
EW2	852984.5	228179.1	-85	-195	110	-28.2	
EW3	853178.7	228216.3	-80	-195	115	-29.5	
EW4	853373.0	228227.0	-80	-195	115	-29.5	
EW5	853569.9	228203.0	-80	-195	115	-29.5	
EW6	853713.6	227969.0	-80	-195	115	-29.5	
EW7	853881.2	227966.3	-80	-195	115	-29.5	
EW8	854051.5	227961.0	-80	-195	115	-29.5	
EW9	854219.1	227953.0	-80	-195	115	-29.5	
EW10	854378.8	227950.3	-80	-195	115	-29.5	
<i>Southern Fence Injection Wells</i>							292.3
IW1	852561.4	227585.9	20	10	10	26.6	
IW2	852723.7	227668.4	20	10	10	26.6	
IW3	852910.0	227740.2	20	10	10	26.6	
IW4	853106.9	227766.8	20	10	10	26.6	
IW5	853303.8	227737.5	20	10	10	26.6	
IW6	853476.7	227689.7	20	10	10	26.6	
IW7	853657.7	227655.1	20	10	10	26.6	
IW8	853841.3	227687.0	20	10	10	26.6	
IW9	854016.9	227745.5	20	10	10	26.6	
IW10	854200.5	227756.2	20	10	10	26.6	
IW11	854344.2	227801.4	20	10	10	26.6	
<i>Northern Fence Extraction Wells</i>							-307.7
EW1	853659.9	229310.5	-50	-180	130	-33.3	
EW2	853782.1	229406.1	-50	-180	130	-33.3	
EW3	853904.3	229496.4	-50	-180	130	-33.3	
EW4	854068.2	229545.0	-50	-175	125	-32.1	
EW5	854238.5	229603.6	-50	-175	125	-32.1	
EW6	854414.2	229648.8	-50	-175	125	-32.1	
EW7	854603.1	229630.2	-50	-175	125	-32.1	
EW8	854776.0	229542.4	-50	-170	120	-30.8	
EW9	854952.2	229566.3	-70	-170	100	-25.6	
EW10	855109.2	229595.6	-70	-160	90	-23.1	
<i>Northern Fence Injection Wells</i>							307.7
IW1	852825.3	228856.1	10	0	10	34.2	
IW2	852831.3	228582.1	10	0	10	34.2	
IW3	852777.6	228332.0	10	0	10	34.2	
IW4	852658.5	228034.1	10	0	10	34.2	
IW5	855111.8	229318.9	0	-10	10	34.2	
IW6	855274.2	229366.8	0	-10	10	34.2	
IW7	855441.8	229412.0	0	-10	10	34.2	
IW8	855614.8	229446.6	0	-10	10	34.2	
IW9	855753.1	229470.6	0	-10	10	34.2	
Total extraction:							-600.0
Total injection:							600.0

ft = feet

msl = mean sea level

gpm = gallons per minute

**Table B5-2**  
**Well Layout of Alternative 5 for the FS-28 Plume**

Well ID	Easting (ft)	Northing (ft)	Screen Top (ft msl)	Screen Bottom (ft msl)	Length (ft)	Pumping (gpm)	Total Pumping (gpm)
<i>Extraction Wells</i>							-400.0
EW1	852794.2	228158.5	-85	-195	110	-38.6	
EW2	852984.5	228179.1	-85	-195	110	-38.6	
EW3	853178.7	228216.3	-80	-195	115	-40.4	
EW4	853373.0	228227.0	-80	-195	115	-40.4	
EW5	853569.9	228203.0	-80	-195	115	-40.4	
EW6	853713.6	227969.0	-80	-195	115	-40.4	
EW7	853881.2	227966.3	-80	-195	115	-40.4	
EW8	854051.5	227961.0	-80	-195	115	-40.4	
EW9	854219.1	227953.0	-80	-195	115	-40.4	
EW10	854378.8	227950.3	-80	-195	115	-40.4	
<i>Injection Wells</i>							400.0
IW1	852561.4	227585.9	20	10	10	36.4	
IW2	852723.7	227668.4	20	10	10	36.4	
IW3	852910.0	227740.2	20	10	10	36.4	
IW4	853106.9	227766.8	20	10	10	36.4	
IW5	853303.8	227737.5	20	10	10	36.4	
IW6	853476.7	227689.7	20	10	10	36.4	
IW7	853657.7	227655.1	20	10	10	36.4	
IW8	853841.3	227687.0	20	10	10	36.4	
IW9	854016.9	227745.5	20	10	10	36.4	
IW10	854200.5	227756.2	20	10	10	36.4	
IW11	854344.2	227801.4	20	10	10	36.4	

ft = feet

msl = mean sea level

gpm = gallons per minute

**Table B5-3**  
**Well Layout of Alternative 6 for the FS-28 Plume**

Well ID	Easting (ft)	Northing (ft)	Screen Top (ft msl)	Screen Bottom (ft msl)	Length (ft)	Pumping (gpm)	Total Pumping (gpm)
<i>Extraction Wells</i>							-600.0
EW1	852938.0	228191.0	-80	-195	115	-125.5	
EW2	853657.0	228058.3	-80	-195	115	-125.5	
EW3	854368.9	227878.7	-80	-195	115	-125.5	
EW4	854459.9	228606.0	-70	-185	115	-125.5	
EW5	853966.0	229508.0	-70	-160	90	-98.2	
<i>Injection Wells</i>							600.0
IW1	853104.7	227696.8	10	0	10	200.0	
IW2	853641.3	227633.2	10	0	10	200.0	
IW3	854023.3	227751.4	10	0	10	200.0	

ft = feet

msl = mean sea level

gpm = gallons per minute

**Table B5-4**  
**Well Layout of Alternative 7 for the FS-28 Plume**

Well ID	Easting (ft)	Northing (ft)	Screen Top (ft msl)	Screen Bottom (ft msl)	Length (ft)	Pumping (gpm)	Total Pumping (gpm)
<i>Extraction Wells</i>							-600.0
EW1	852604.5	226996.7	-120	-210	90	-163.6	
EW2	853432.2	227078.6	-100	-210	110	-200.0	
EW3	854068.8	226951.3	-80	-210	130	-236.4	
<i>Return flow to Coonamessett Pond</i>							300.0
IW3	853560.0	227210.0	n/a	n/a	0	300.0	

ft = feet

msl = mean sea level

gpm = gallons per minute

n/a = not applicable

**Note**

There is also a return flow of 300 gpm to the Coonamessett River, which is not listed because rivers are modeled as drains. Drains do not permit flow back into the ground-water system.

**Table B6-1**  
**Well Layout of the CS-21 Plume Expedited Capture and  
FS-29 Full Capture Alternatives**

Well ID	Easting (ft)	Northing (ft)	Screen Top (ft msl)	Screen Bottom (ft msl)	Length (ft)	Expedited Capture Pumping (gpm)	FS-29-Full Capture Pumping (gpm)
<i>CS-21 Plume</i>							
RW-A1	846200.0	232710.0	-145	-175	30	-200	n/a
EW-A1	846200.0	232710.0	-145	-175	30	n/a	-300
EW-A2	848280.0	233700.0	-102	-190	88	-400	-300
EW-A3	849790.0	234630.0	-17	-56	39	-200	-150
EW-A4	849790.0	234630.0	-72	-162	90	-200	-150
EW-A5	850770.0	235810.0	-16	-67	51	-200	-150
EW-A6	850770.0	235810.0	-71	-135	64	-200	-150
					Total	-1400	-1200
<i>CS-20 Plume</i>							
EW-B1	852660.0	231540.0	-51	-131	80	-200	-200
EW-B2	853350.0	233060.0	-51	-149	98	-200	-200
EW-B3	853930.0	234390.0	-42	-142	100	-200	-200
					Total	-600	-600
<i>CS-4 Plume</i>							
EW-C1	854990.0	232000.0	-59	-89	30	-100	-100
EW-C2	855170.0	232890.0	-74	-105	31	-100	-100
EW-C3	855180.0	233740.0	-48	-71	23	-100	-100
					Total	-300	-300
<i>FS-29 plume</i>							
EW-D1	843810.0	230790.0	-64	-105	41	n/a	-300
EW-D2	846150.0	231620.0	-63	-123	60	n/a	-300
					Total	n/a	-600

n/a = not applicable; not included in the alternative

ft = feet

msl = mean sea level

gpm = gallons per minute

**Table B6-2**  
**Performance Summary of Alternatives for the FS-29 Plume**

Alternative	CS-21 Pumping (gpm)	FS-29 Pumping (gpm)	Capture by Extraction Wells (% of plume) <sup>1</sup>			
			5 yr	10 yr	20 yr	30 yr
Baseline	0	0	n/t	5.5	n/t	21.4
Expedited Capture	1400	0	2.0	8.8	18.2	22.8
FS-29-Full Capture	1200	600	31.0	56.5	86.5	96

gpm = gallons per minute

yr = year

n/t = not tabulated.

**Note**

1. For the baseline scenario, discharge to surface water is tabulated.

**Table B8-1**  
**Performance Summary of Alternatives 4 through 7 for the FS-28 Plume**

Alternative	No. of Extraction Wells	No. of Injection Wells	Pumping (gpm)	Discharge to Coonamessett Pond (%)	Capture by Extraction Wells (%)	90% Complete (yr)	95% Complete (yr)	Completion for the FS-28 EW-1 system (yr)
Baseline	n/a	n/a	n/a	20.8	n/a	n/a	n/a	18
4	20	21	600	4.5	95.2	5.0	7.8	14
5	10	11	400	10.0	89.9	5.3	6.5	13
6	5	3	600	2.9	97.1	3.3	4.0	11
7	3	0	600	10.3	89.6	7.0	9.0	9.0

gpm = gallons per minute

yr = year

## **APPENDIX C**

### **Cost Estimates**

## Notes Concerning Cost Estimates

**Escalated** = Values in this column represent future (post-construction) costs that have been increased at a rate of five percent annually. This escalation represents inflation and the values represent costs in terms of the actual dollars as they will be spent.

**PV** = Present value. Values in this column have been discounted to their present worth based on a discount rate of seven percent. The specified rate of seven percent represents a real discount rate in that it approximates the marginal pretax rate of return on an average investment in the private sector in recent years and has been adjusted to eliminate the effect of expected inflation. The present value for a series of future year costs was calculated by applying the formula:

$$PV = \sum_{j=1}^n \frac{values_j}{(1 + Rate)^j}.$$

In this case Rate = 0.07, values = the cash flow in any given year, and j = the year in which the cash flow occurred. For instance, a cost of \$10,000 for each of the next three years would have a present value of:

$$PV = \left( \frac{10000}{1.07^1} \right) + \left( \frac{10000}{1.07^2} \right) + \left( \frac{10000}{1.07^3} \right) = 26243.$$

**Reparations for Lost Crops** - Costs for Alternative 1, No Remedial Action with Long-term Monitoring, for the FS-28 plume do not include reparations to growers for lost crops.

# FS-28 Plume Remedial Alternatives Cost Summary

WBS	ALTERNATIVE 1 [WBS - 50.1.]	Escalated	Subtotal (PV)	Total (PV)
	<b>No Remedial Action with Long-Term Monitoring</b>			
01 02	<b>PLANS AND DESIGN</b>			<b>\$14,136</b>
01 02 01	Project Execution Plan		\$14,136	
02 02	<b>PROJECT INTEGRATION</b>			<b>\$19,403</b>
02 02 01	Independent Planning/Reporting Oversight		\$6,160	
02 02 02	Independent Fieldwork Oversight		\$9,350	
02 02 03	Vehicles		\$3,893	
03 01	<b>MOBILIZATION</b>			<b>\$35,880</b>
03 01 01	Sampling and Analysis Plan		\$32,262	
03 01 02	Orientation and Training		\$3,262	
03 01 03	Personal Protective Equipment		\$356	
04 01	<b>BASELINE ENVIRONMENTAL SAMPLING (2 Qtr. Prior to Monitoring)</b>			<b>\$152,510</b>
04 01 01	Groundwater Sampling		\$18,900	
04 01 02	Surface Water Sampling		\$33,050	
04 01 03	Sample Analysis		\$44,850	
04 01 04	Baseline Report		\$55,710	
13 03	<b>OPERATIONS AND MAINTENANCE</b>			<b>\$809,857</b>
13 03 01	Monitoring Well Maintenance	\$64,704	\$23,136	
13 03 02	Monitoring Well Closing	\$111,404	\$39,834	
13 03 03	Maintenance and Monitoring Integration	\$2,088,830	\$746,887	
14 03	<b>MONITORING</b>			<b>\$2,345,871</b>
14 03 01	Well Sampling, Years 1 to 18	\$1,085,558	\$352,068	
14 03 03	Surface Water Sampling, Years 1 to 18	\$2,195,930	\$712,183	
14 03 05	Sample Analysis, Years 1 to 18	\$2,839,976	\$921,060	
14 03 08	Annual Sampling and Analysis Report	\$817,668	\$292,367	
14 03 09	CERCLA 5-Year Reporting	\$190,715	\$68,192	
15 02	<b>CONTRACT/BASELINE MANAGEMENT</b>			<b>\$45,750</b>
15 02 01	Procurement		\$3,520	
15 02 02	Project Management		\$45,750	
			<b>\$3,426,927</b>	<b>\$3,423,407</b>



### FS-28 Plume Remedial Alternatives Cost Summary

WBS	ALTERNATIVE 3 [WBS - 50.3.]	Escalated	Subtotal (PV)	Total (PV)
	Continued Treatment System Operations			
02 02	<b>PROJECT INTEGRATION</b>			<b>\$36,960</b>
02 02 01	Independent Planning/Reporting Oversight		\$36,960	
13 03	<b>OPERATIONS AND MAINTENANCE</b>			<b>\$4,479,683</b>
13 03 01	ETR Continued Operations and Maintenance	\$10,730,731	\$3,836,907	
13 03 02	Monitoring Well Maintenance	\$64,704	\$23,136	
13 03 04	Maintenance and Monitoring Integration	\$1,732,955	\$619,640	
14 03	<b>MONITORING</b>			<b>\$2,470,830</b>
14 03 01	Well Sampling, Years 1 to 18	\$1,085,558	\$352,068	
14 03 03	Surface Water Sampling, Years 1 to 18	\$1,870,262	\$606,563	
14 03 05	Sample Analysis, Years 1 to 18	\$2,647,677	\$858,694	
14 03 07	Treatment System Performance Sampling and Analysis	\$311,707	\$111,455	
14 03 10	CERCLA 5-Year Reporting	\$196,382	\$70,219	
14 03 11	Sampling and Operations Management Report	\$1,319,578	\$471,832	
15 02	<b>CONTRACT MANAGEMENT</b>			<b>\$86,080</b>
15 02 01	Procurement		\$14,080	
15 02 02	Project Management		\$72,000	
	<b>TOTAL</b>		<b>\$7,073,553</b>	<b>\$7,073,553</b>

### FS-28 Plume Remedial Alternatives Cost Summary

WBS	ALTERNATIVE 6 [WBS - 50.6.]	Escalated	Subtotal (PV)	Total (PV)
	<b>Continued Remedial Operations with Capture North of the Western Arm of Coonamessett Pond</b>			
02 02	<b>PROJECT INTEGRATION</b>			<b>\$36,960</b>
02 02 01	Independent Planning/Reporting Oversight		\$36,960	
04 01	<b>ADDITIONAL CONSTRUCTION</b>			<b>\$8,772,184</b>
04 01 01	Engineering		\$431,984	
04 01 02	Wellfield Construction		\$5,962,422	
04 01 03	Treatment System Construction		\$1,747,443	
04 01 04	Startup and Initial Operations		\$64,419	
04 01 05	Initial Performance Monitoring		\$98,564	
04 01 06	Modeling		\$151,573	
04 01 07	Baseline Ecological Sampling		\$315,779	
13 03	<b>OPERATIONS AND MAINTENANCE</b>			<b>\$3,339,437</b>
13 03 01	ETR Continued Operations and Maintenance	\$5,418,993	\$2,860,271	
13 03 02	Monitoring Well Maintenance	\$32,676	\$17,247	
13 03 04	Maintenance and Monitoring Integration	\$875,138	\$461,918	
14 03	<b>OPERATIONAL MONITORING</b>			<b>\$1,849,935</b>
14 03 01	Well Sampling, Years 1 to 11	\$548,204	\$262,454	
14 03 03	Surface Water Sampling, Years 1 to 11	\$944,478	\$452,170	
14 03 05	Samples Analysis, Years 1 to 11	\$1,337,071	\$640,124	
14 03 07	Treatment System Performance Sampling and Analysis	\$157,411	\$83,085	
14 03 10	CERCLA 5-Year Reporting	\$114,373	\$60,369	
14 03 11	Sampling and Operations Management Report	\$666,384	\$351,733	
15 02	<b>CONTRACT MANAGEMENT</b>			<b>\$86,080</b>
15 02 01	Procurement		\$14,080	
15 02 02	Project Management		\$72,000	
16 01	<b>ADDITIONAL OPERATIONS AND MAINTENANCE</b>			<b>\$1,092,894</b>
16 01 01	Northern System Operations and Maintenance	\$1,390,675	\$1,092,894	
	<b>TOTAL</b>		<b>\$15,177,490</b>	<b>\$15,177,490</b>

# FS-28 Plume Remedial Alternatives Cost Summary

WBS	ALTERNATIVE 7 [WBS - 50.7.]	Escalated	Subtotal (PV)	Total (PV)
	Continued Remedial Operations with Additional Extraction and Treatment in the Souza Conservation Area			
02 02	<b>PROJECT INTEGRATION</b>			<b>\$36,960</b>
02 02 01	Independent Planning/Reporting Oversight		\$36,960	
04 01	<b>ADDITIONAL CONSTRUCTION</b>			<b>\$5,738,989</b>
04 01 01	Engineering		\$431,984	
04 01 02	Wellfiled Construction		\$2,945,143	
04 01 03	Treatment System Construction		\$1,747,443	
04 01 04	Startup and Initial Operations		\$64,419	
04 01 05	Initial Performance Monitoring		\$82,649	
04 01 06	Modeling		\$151,573	
04 01 07	Baseline Ecological Sampling		\$315,778	
13 03	<b>OPERATIONS AND MAINTENANCE</b>			<b>\$2,901,474</b>
13 03 01	ETR Continued Operations and Maintenance	\$4,205,939	\$2,485,150	
13 03 02	Monitoring Well Maintenance	\$25,361	\$14,985	
13 03 04	Maintenance and Monitoring Integration	\$679,236	\$401,338	
14 03	<b>MONITORING</b>			<b>\$1,601,420</b>
14 03 01	Well Sampling, Years 1 to 9	\$425,488	\$228,033	
14 03 03	Surface Water Sampling, Years 1 to 9	\$733,054	\$392,869	
14 03 05	Samples Analysis, Years 1 to 9	\$1,037,764	\$556,173	
14 03 07	Treatment System Performance Sampling and Analysis	\$122,174	\$72,189	
14 03 10	CERCLA 5-Year Reporting	\$78,788	\$46,553	
14 03 11	Sampling and Operations Management Report	\$517,212	\$305,603	
15 02	<b>CONTRACT MANAGEMENT</b>			<b>\$86,080</b>
15 02 01	Procurement		\$14,080	
15 02 02	Project Management		\$72,000	
16 01	<b>ADDITIONAL OPERATIONS AND MAINTENANCE</b>			<b>\$1,778,750</b>
15 02 02	Operations and Maintenance of Northern System	\$3,010,408	\$1,778,750	
	<b>TOTAL</b>		<b>\$12,143,673</b>	<b>\$12,143,673</b>

### FS-29 Plume Remedial Alternatives Cost Summary

WBS	Alternative 1 [WBS 40.1.]	Escalated	Subtotal (PV)	Total (PV)
	<b>No Remedial Action with Long-Term Monitoring</b>			
<b>01 02</b>	<b>PLANS AND DESIGN</b>			\$14,152
01 02 01	Project Execution Plan (JEG)		\$14,152	
<b>02 02</b>	<b>PROJECT INTEGRATION</b>			\$6,806
02 02 01	Independent Planning/Report Oversight		\$3,850	
02 02 02	Independent Fieldwork Oversight		\$2,090	
02 02 03	Vehicle		\$866	
<b>03 01</b>	<b>MOBILIZATION</b>			\$26,357
03 01 01	Sampling and Analysis Plan		\$24,466	
03 01 02	Orientation and Training		\$1,711	
03 01 03	Personal Protective Equipment		\$180	
<b>04 01</b>	<b>BASELINE ENVIRONMENTAL SAMPLING</b>			\$137,519
04 01 01	Monitoring Well Installation		\$61,650	
04 01 02	Groundwater Sampling		\$21,780	
04 01 03	Samples Analysis		\$17,600	
04 01 04	Interim Sampling Report		\$12,154	
04 01 05	Baseline Report		\$24,335	
<b>13 03</b>	<b>OPERATIONS AND MAINTENANCE</b>			\$336,173
13 03 01	Monitoring Well Maintenance	\$25,065	\$9,470	
13 03 02	Monitoring Well Installation	\$354,013	\$128,598	
13 03 03	Monitoring Well Closing	\$89,537	\$33,830	
13 03 04	Maintenance and Monitoring Integration	\$434,790	\$164,276	
<b>14 03</b>	<b>MONITORING</b>			\$440,264
14 03 01	Well Sampling, Years 1 and 2	\$15,683	\$13,831	
14 03 02	Well Sampling, Years 3 to 17	\$62,450	\$20,882	
14 03 03	Samples Analysis, Years 1 and 2	\$22,694	\$20,015	
14 03 06	Samples Analysis, Years 3 to 17	\$282,154	\$94,349	
14 03 07	Interim Sampling Report	\$24,916	\$21,975	
14 03 08	Annual Sampling and Analysis Report	\$532,235	\$196,215	
14 03 09	CERCLA 5-Year Reporting	\$204,785	\$72,997	
<b>15 02</b>	<b>CONTRACT MANAGEMENT</b>			\$6,776
15 02 01	Procurement		\$1,408	
15 02 02	Project Management		\$5,368	
	<b>TOTAL</b>		<b>\$968,048</b>	<b>\$968,048</b>

### FS-29 Plume Remedial Alternatives Cost Summary

WBS	Alternative 2 [WBS 40.2.]	Escalated	Subtotal (PV)	Total (PV)
	<b>Institutional and Engineering Controls</b>			
<b>01 02</b>	<b>PLANS AND DESIGN</b>			\$14,152
01 02 01	Project Execution Plan (JEG)		\$14,152	
<b>02 02</b>	<b>PROJECT INTEGRATION</b>			\$6,806
02 02 01	Independent Planning/Report Oversight		\$3,850	
02 02 02	Independent Fieldwork Oversight		\$2,090	
02 02 03	Vehicle		\$866	
<b>03 01</b>	<b>MOBILIZATION</b>			\$26,357
03 01 01	Sampling and Analysis Plan		\$24,466	
03 01 02	Orientation and Training		\$1,711	
03 01 03	Personal Protective Equipment		\$180	
<b>04 01</b>	<b>BASELINE ENVIRONMENTAL SAMPLING</b>			\$137,519
04 01 01	Monitoring Well Installation		\$61,650	
04 01 02	Groundwater Sampling		\$21,780	
04 01 03	Samples Analysis		\$17,600	
04 01 04	Interim Sampling Report		\$12,154	
04 01 05	Baseline Report		\$24,335	
<b>05 01</b>	<b>Wellhead Protection</b>			<b>\$2,182,230</b>
05 01 01	Wellhead Treatment and Sentinel Well Construction		\$530,000	
05 01 02	Annual Expenses	\$4,372,965	\$1,652,230	
<b>13 03</b>	<b>OPERATIONS AND MAINTENANCE</b>			\$336,173
13 03 01	Monitoring Well Maintenance	\$25,065	\$9,470	
13 03 02	Monitoring Well Installation	\$354,013	\$128,598	
13 03 03	Monitoring Well Closing	\$89,537	\$33,830	
13 03 04	Maintenance and Monitoring Integration	\$434,790	\$164,276	
<b>14 03</b>	<b>MONITORING</b>			\$440,264
14 03 01	Well Sampling, Years 1 and 2	\$15,683	\$13,831	
14 03 02	Well Sampling, Years 3 to 17	\$62,450	\$20,882	
14 03 03	Samples Analysis, Years 1 and 2	\$22,694	\$20,015	
14 03 06	Samples Analysis, Years 3 to 17	\$282,154	\$94,349	
14 03 07	Interim Sampling Report	\$24,916	\$21,975	
14 03 08	Annual Sampling and Analysis Report	\$532,235	\$196,215	
14 03 09	CERCLA 5-Year Reporting	\$204,785	\$72,997	
<b>15 02</b>	<b>CONTRACT MANAGEMENT</b>			\$6,776
15 02 01	Procurement		\$1,408	
15 02 02	Project Management		\$5,368	
	<b>TOTAL</b>		<b>\$3,150,278</b>	<b>\$3,150,278</b>

### FS-29 Plume Remedial Alternatives Cost Summary

WBS	Alternative 3 [WBS 40.3.]	Escalated	Subtotal (PV)	Total (PV)
	<b>Extraction, Treatment and Reinjection for Plume Capture</b>			
<b>01 02</b>	<b>PLANS AND DESIGN</b>			<b>\$ 92,764</b>
01 02 01	Project Execution Plan (JEG)	\$	45,062	
01 02 02	Design Report	\$	47,702	
<b>02 02</b>	<b>PROJECT INTEGRATION</b>			<b>\$ 100,517</b>
02 02 01	Independent Planning/Report Oversight	\$	15,400	
02 02 02	Independent Fieldwork Oversight	\$	16,170	
02 02 03	Construction Oversight	\$	17,600	
02 02 04	Operations Oversight	\$	46,200	
02 02 05	Vehicle	\$	5,147	
<b>03 01</b>	<b>MOBILIZATION</b>			<b>\$ 197,763</b>
03 01 01	Sampling and Analysis Plan	\$	29,966	
03 01 02	Establish Contractor Facility	\$	34,400	
03 01 03	Equipment/Material Transport and Storage	\$	111,690	
03 01 04	Access to Drilling (approx. 1800 yd)	\$	9,760	
03 01 05	Orientation and Training	\$	1,711	
03 01 06	Personal Protective Equipment	\$	10,236	
<b>04 01</b>	<b>BASELINE ENVIRONMENTAL SAMPLING</b>			<b>\$ 1,081,674</b>
04 01 01	Data Gap Boring and Monitoring Well Installation	\$	920,550	
04 01 02	Groundwater Sampling	\$	19,140	
04 01 03	Samples Analysis	\$	93,065	
04 01 04	Interim Sampling Report	\$	12,154	
04 01 05	Baseline Report	\$	36,765	
<b>06 01</b>	<b>TREATMENT SYSTEM CONSTRUCTION</b>			<b>\$ 2,932,640</b>
06 01 01	GAC/Greensand/Sedimentation Modular Unit	\$	2,833,710	
06 01 02	Instrumentation	\$	98,930	
<b>08 01</b>	<b>WELL CONSTRUCTION</b>			<b>\$ 1,544,050</b>
08 01 01	Extraction Wells	\$	467,050	
08 01 02	Infiltration Gallery	\$	100,000	
08 01 03	Piping from Wells and To Gallery	\$	977,000	
<b>09 01</b>	<b>ETR OPERATION AND VERIFICATION</b>			<b>\$ 336,864</b>
09 01 01	Treatment Unit Operation	\$	199,675	
09 01 02	Baseline Operation for Modular System	\$	27,500	
09 01 03	Performance Monitoring, Years 1 to 8	\$	61,624	
09 01 04	Operations Verification Report	\$	48,066	
<b>13 03</b>	<b>OPERATIONS AND MAINTENANCE</b>			<b>\$ 3,958,695</b>
13 03 01	Treatment System Operations and Maintenance	\$	2,446,740	

**FS-29 Plume Remedial Alternatives Cost Summary**

<b>Alternative 3 (continued)</b>				<b>Escalated</b>	<b>Subtotal (PV)</b>	<b>Total (PV)</b>
13	03	02	Monitoring Well Maintenance	\$	5,792	
13	03	02	Monitoring Well Installation	\$	83,292	
13	03	03	Monitoring Well Closing	\$	20,691	
13	03	04	Maintenance and Monitoring Integration	\$	1,402,180	
<b>14</b>	<b>03</b>	<b>MONITORING</b>				<b>\$ 302,606</b>
14	03	01	Well Sampling, Years 1 and 2	\$	14,193	
14	03	02	Well Sampling, Years 3 to 8	\$	10,929	
14	03	03	Samples Analysis, Years 1 and 2	\$	22,040	
14	03	06	Samples Analysis, Years 3 to 8	\$	49,148	
14	03	07	Interim Sampling Report	\$	32,317	
14	03	08	Annual Sampling and Analysis Report	\$	125,585	
14	03	09	CERCLA 5-Year Reporting	\$	48,395	
<b>15</b>	<b>02</b>	<b>CONTRACT MANAGEMENT</b>				<b>\$ 547,250</b>
15	02	01	Procurement	\$	176,000	
15	02	02	Project Management	\$	371,250	
<b>TOTAL</b>				<b>\$</b>	<b>11,094,823</b>	<b>\$ 11,094,823</b>

### FS-29 Plume Remedial Alternatives Cost Summary

WBS	Alternative 7 [WBS 40.7.]	Escalated	Subtotal (PV)	Total (PV)
	<b>Extraction Treatment and Reinjection to Capture the Central Portion of the FS-29 Plume</b>			
<b>01 02</b>	<b>PLANS AND DESIGN</b>			<b>\$ 92,764</b>
01 02 01	Project Execution Plan (JEG)	\$	45,062	
01 02 02	Design Report	\$	47,702	
<b>02 02</b>	<b>PROJECT INTEGRATION</b>			<b>\$ 100,517</b>
02 02 01	Independent Planning/Report Oversight	\$	15,400	
02 02 02	Independent Fieldwork Oversight	\$	16,170	
02 02 03	Construction Oversight	\$	17,600	
02 02 04	Operations Oversight	\$	46,200	
02 02 05	Vehicle	\$	5,147	
<b>03 01</b>	<b>MOBILIZATION</b>			<b>\$ 192,908</b>
03 01 01	Sampling and Analysis Plan	\$	29,966	
03 01 02	Establish Contractor Facility	\$	34,400	
03 01 03	Equipment/Material Transport and Storage	\$	111,690	
03 01 04	Access to Drilling (approx. 1800 yd)	\$	4,905	
03 01 05	Orientation and Training	\$	1,711	
03 01 06	Personal Protective Equipment	\$	10,236	
<b>04 01</b>	<b>BASELINE ENVIRONMENTAL SAMPLING</b>			<b>\$ 846,752</b>
04 01 01	Data Gap Boring and Monitoring Well Installation	\$	690,413	
04 01 02	Groundwater Sampling	\$	14,355	
04 01 03	Samples Analysis	\$	93,065	
04 01 04	Interim Sampling Report	\$	12,154	
04 01 05	Baseline Report	\$	36,765	
<b>06 01</b>	<b>TREATMENT SYSTEM CONSTRUCTION</b>			<b>\$ 2,932,640</b>
06 01 01	GAC/Greensand/Sedimentation Modular Unit	\$	2,833,710	
06 01 02	Instrumentation	\$	98,930	
<b>08 01</b>	<b>WELL CONSTRUCTION</b>			<b>\$ 1,257,550</b>
08 01 01	Extraction Wells	\$	467,050	
08 01 02	Infiltration Gallery	\$	100,000	
08 01 03	Piping from Wells and To Gallery	\$	690,500	
<b>09 01</b>	<b>ETR OPERATION AND VERIFICATION</b>			<b>\$ 324,431</b>
09 01 01	Treatment Unit Operation	\$	199,675	
09 01 02	Baseline Operation for Modular System	\$	27,500	
09 01 03	Performance Monitoring, Years 1 to 6	\$ 77,391	\$ 49,191	
09 01 04	Operations Verification Report		\$ 48,066	
<b>13 03</b>	<b>OPERATIONS AND MAINTENANCE</b>			<b>\$ 3,226,280</b>



### FS-29 Plume Remedial Alternatives Cost Summary

Alternative 7 (continued)				Escalated	Subtotal (PV)	Total (PV)
13	03	01	Treatment System Operations and Maintenance	\$ 2,787,084	\$ 1,953,090	
13	03	02	Monitoring Well Maintenance	\$ 6,598	\$ 4,624	
13	03	02	Monitoring Well Installation	\$ 354,013	\$ 128,598	
13	03	03	Monitoring Well Closing	\$ 33,088	\$ 20,691	
13	03	04	Maintenance and Monitoring Integration	\$ 1,597,225	\$ 1,119,279	
14	03		<b>MONITORING</b>			\$ 496,309
14	03	01	Well Sampling, Years 1 and 2	\$ 16,093	\$ 14,193	
14	03	02	Well Sampling, Years 3 to 10	\$ 41,841	\$ 20,882	
14	03	03	Samples Analysis, Years 1 and 2	\$ 24,990	\$ 22,040	
14	03	06	Samples Analysis, Years 3 to 10	\$ 225,330	\$ 93,911	
14	03	07	Interim Sampling Report	\$ 36,642	\$ 32,317	
14	03	08	Annual Sampling and Analysis Report	\$ 650,917	\$ 239,969	
14	03	09	CERCLA 5-Year Reporting	\$ 204,785	\$ 72,997	
15	02		<b>CONTRACT MANAGEMENT</b>			\$ 547,250
15	02	01	Procurement		\$ 176,000	
15	02	02	Project Management		\$ 371,250	
<b>TOTAL</b>					\$ 10,017,401	\$ 10,017,401

# **APPENDIX D**

## **Post-Remedial Investigation Data Acquisition**

## **FS-28 PLUME**

AFCEE resampled seven wells (69MW1271, 69MW1275, 69MW1400A,B, 69MW1401, 69MW1402, and 69MW1411) located north of the western arm of Coonamessett Pond and one well located south of the western arm of Coonamessett Pond (69MW1283B). All resampled wells were screened in the FS-28 plume. The locations of these wells are shown in Figure 2-6 in the *Final Southwest Operable Unit Remedial Investigation* (AFCEE, May 1999, AFC-J23-35Q86101-M14-0006). The purpose of resampling was to confirm that EDB concentrations in the FS-28 plume are being reduced over time. The 1999 data support this trend.

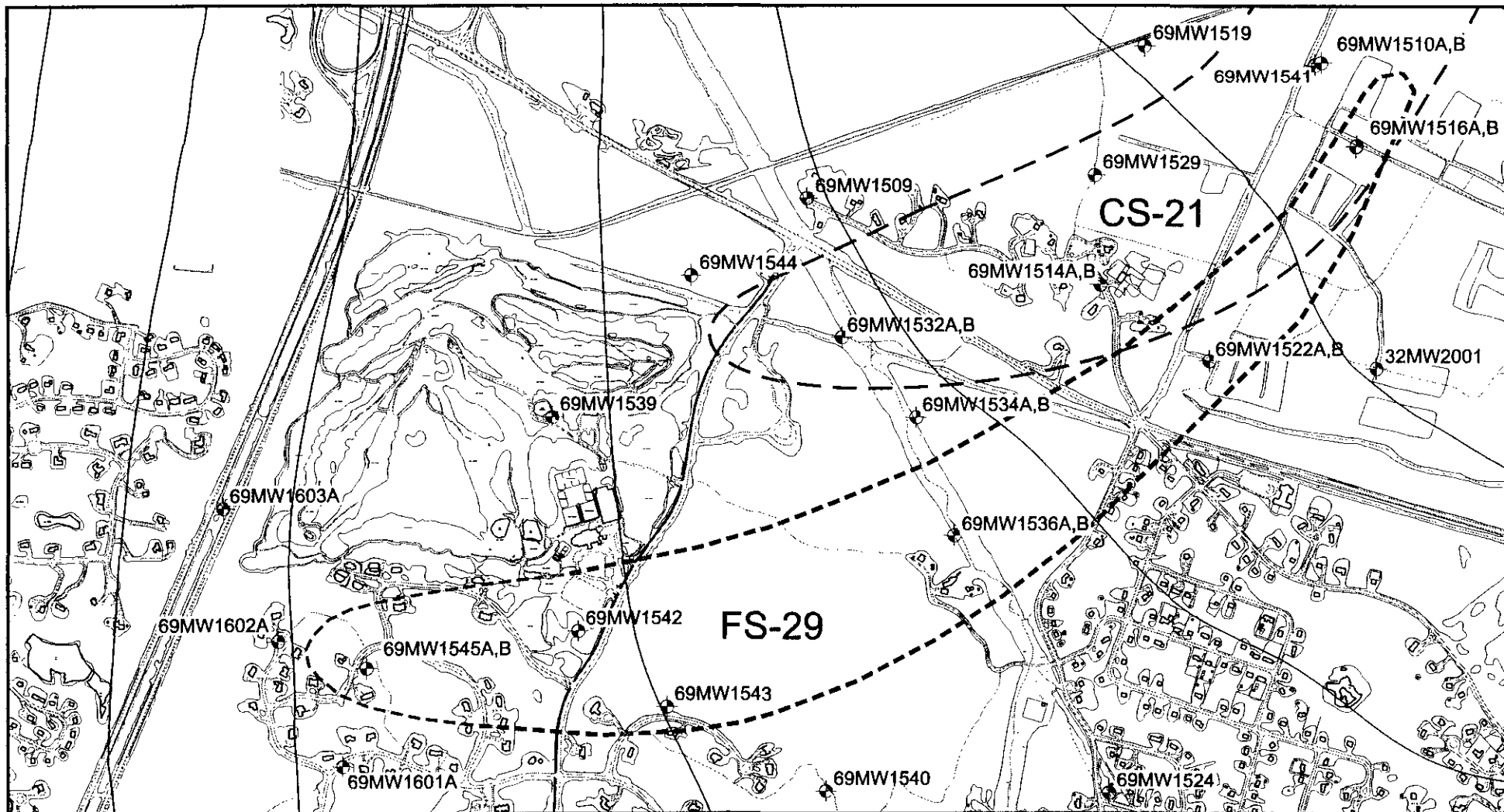
## **FS-29 PLUME**

At the conclusion of the SWOU RI field program, the leading edge of the FS-29 plume had not been defined. The furthest downgradient boring, 69MW1545A,B, showed that about 30 feet of water had low levels of EDB, with concentrations ranging from 0.006 J to 0.033 µg/L (the J qualifier indicates an estimated result). The upper lobe of the FS-29 plume was not detected at this location, and there was no carbon tetrachloride detected. Although the contaminant distribution suggested that 69MW1545A,B was near the leading edge of the plume, clean borings needed to be drilled downgradient to complete the plume definition.

Three borings, 69MW1601A, 69MW1602A, and 69MW1603A (Figure D-1), were installed in April 1999 to define the leading edge of the FS-29 plume. Borehole water samples were collected every 10 feet from the top of the saturated zone to the bedrock interface. All samples were screened for target VOCs (method 8260) and low-level EDB (method 504) at the on-site laboratory. None of the samples collected in these three borings contained detectable concentrations of EDB or carbon tetrachloride, the FS-29 plume contaminants of concern. One monitoring well was installed in each boring, screened at the elevation consistent with the EDB distribution at 69MW1545. The VOC and EDB analysis of samples collected from these wells were also below detection limits for the FS-29 plume contaminants of concern.

Two compounds were detected in the borewater samples collected from 69MW1601A. Low levels of ethylbenzene (ranging from 0.359 J  $\mu\text{g/L}$  to 0.581 J  $\mu\text{g/L}$ ) were present in the samples collected from 112.5 to 162.5 feet below ground. The presence of ethylbenzene in these samples is not considered attributable to MMR because (1) this fuel-related compound is readily degraded in aerobic groundwater as is present at the site and could not have migrated the several miles from the MMR, (2) the samples containing ethylbenzene were from the upper six intervals sampled at that location, which is inconsistent with MMR-related contamination that is generally much deeper, (3) because the concentrations collected from the six borings were very close in magnitude, sampling equipment contamination is suspected, and (4) gasoline containing ethylbenzene was used by the drilling equipment on the site and cross-contamination is very likely to occur unless careful precautions are taken to prevent it. Also, one sample collected from 132.5 feet below ground contained 1.47  $\mu\text{g/L}$  of 1,1,1-trichloroethane. This one result is not considered to be attributable to MMR because it was collected from the upper part of the water column, and MMR-related contamination is generally much deeper, often underlying tens of feet of clean water. A closer area would be expected as the source of this result.

Data tables and boring logs are attached.



Legend



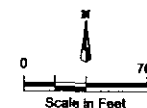
Monitoring Well



JACOBS ENGINEERING

Monitoring Wells at  
CS-21 and FS-29

Massachusetts Military Reservation  
Cape Cod, Massachusetts



7/1/00 mm File: FS29wells.dwg Figure D-1

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Ethylene Dibromide Analysis of 1999 Water Samples From Wells in the Northern Part of the FS-28 Plume

Location	Date	Depth	Type	Test	Analyte	Result	DL	RL	Units	Qual
69MW1400A	04/21/1999	152	N1	E504	1,2-DIBROMOETHANE (EDB)	0.05	0.005	0.01	µG/L	
69MW1400B	04/21/1999	203	N1	E504	1,2-DIBROMOETHANE (EDB)	0.035	0.005	0.01	µG/L	
69MW1401	04/21/1999	157	N1	E504	1,2-DIBROMOETHANE (EDB)	0.885	0.025	0.05	µG/L	
69MW1401	04/21/1999	157	FD1	E504	1,2-DIBROMOETHANE (EDB)	0.865	0.025	0.05	µG/L	
69MW1275	04/27/1999	123	N1	E504	1,2-DIBROMOETHANE (EDB)	0.04	0.005	0.01	µG/L	
69MW1402	04/27/1999	127	N1	E504	1,2-DIBROMOETHANE (EDB)	0.038	0.005	0.01	µG/L	
69MW1411	04/27/1999	221.82	N1	E504	1,2-DIBROMOETHANE (EDB)	0.035	0.005	0.01	µG/L	
69MW1283B	04/28/1999	224.28	N1	E504	1,2-DIBROMOETHANE (EDB)	6.13	0.2	0.4	µG/L	
69MW1271	04/28/1999	151.48	N1	E504	1,2-DIBROMOETHANE (EDB)	0.016	0.005	0.01	µG/L	

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Analysis of Water Samples From New FS-29 Wells

Location	Date	Depth	Matrix	Test	Analyte	Result	DL	RL	Units	Qual
69MW1601A	05/11/99	252.3	WG	E504	1,2-DIBROMOETHANE (EDB)	ND	0.005	0.01	µG/L	U
69MW1601A	05/19/99	251.89	WG	E504	1,2-DIBROMO-3-CHLOROPROPANE	ND	0.0031	0.01	µG/L	U
69MW1601A	05/19/99	251.89	WG	E504	1,2-DIBROMOETHANE (EDB)	ND	0.0027	0.01	µG/L	U
69MW1601A	05/19/99	251.89	WG	CVOL	1,1,1-TRICHLOROETHANE	ND	0.094	1	µG/L	U
69MW1601A	05/19/99	251.89	WG	CVOL	1,1,2,2-TETRACHLOROETHANE	ND	0.14	1	µG/L	U
69MW1601A	05/19/99	251.89	WG	CVOL	1,1,2-TRICHLOROETHANE	ND	0.098	1	µG/L	U
69MW1601A	05/19/99	251.89	WG	CVOL	1,1-DICHLOROETHANE	ND	0.13	1	µG/L	U
69MW1601A	05/19/99	251.89	WG	CVOL	1,1-DICHLOROETHENE	ND	0.13	1	µG/L	U
69MW1601A	05/19/99	251.89	WG	CVOL	1,2,4-TRICHLOROBENZENE	ND	0.083	1	µG/L	U
69MW1601A	05/19/99	251.89	WG	CVOL	1,2-DIBROMOETHANE (EDB)	ND	0.16	1	µG/L	U
69MW1601A	05/19/99	251.89	WG	CVOL	1,2-DICHLOROBENZENE	ND	0.12	1	µG/L	U
69MW1601A	05/19/99	251.89	WG	CVOL	1,2-DICHLOROETHANE	ND	0.1	1	µG/L	U
69MW1601A	05/19/99	251.89	WG	CVOL	1,2-DICHLOROPROPANE	ND	0.1	1	µG/L	U
69MW1601A	05/19/99	251.89	WG	CVOL	1,3-DICHLOROBENZENE	ND	0.093	1	µG/L	U
69MW1601A	05/19/99	251.89	WG	CVOL	1,4-DICHLOROBENZENE	ND	0.097	1	µG/L	U
69MW1601A	05/19/99	251.89	WG	CVOL	2-HEXANONE	ND	0.53	5	µG/L	U
69MW1601A	05/19/99	251.89	WG	CVOL	BENZENE	ND	0.099	1	µG/L	U
69MW1601A	05/19/99	251.89	WG	CVOL	BROMOCHLOROMETHANE	ND	0.17	1	µG/L	U
69MW1601A	05/19/99	251.89	WG	CVOL	BROMODICHLOROMETHANE	ND	0.14	1	µG/L	U
69MW1601A	05/19/99	251.89	WG	CVOL	BROMOFORM	ND	0.11	1	µG/L	U
69MW1601A	05/19/99	251.89	WG	CVOL	BROMOMETHANE	ND	0.13	1	µG/L	U
69MW1601A	05/19/99	251.89	WG	CVOL	CARBON DISULFIDE	ND	0.11	1	µG/L	U
69MW1601A	05/19/99	251.89	WG	CVOL	CARBON TETRACHLORIDE	ND	0.1	1	µG/L	U
69MW1601A	05/19/99	251.89	WG	CVOL	CHLOROBENZENE	ND	0.1	1	µG/L	U
69MW1601A	05/19/99	251.89	WG	CVOL	CHLOROETHANE	ND	0.15	1	µG/L	U
69MW1601A	05/19/99	251.89	WG	CVOL	CHLOROFORM	ND	0.11	1	µG/L	U
69MW1601A	05/19/99	251.89	WG	CVOL	CHLOROMETHANE	ND	0.13	1	µG/L	U
69MW1601A	05/19/99	251.89	WG	CVOL	CIS-1,2-DICHLOROETHENE	ND	0.13	1	µG/L	U
69MW1601A	05/19/99	251.89	WG	CVOL	CIS-1,3-DICHLOROPROPENE	ND	0.12	1	µG/L	U
69MW1601A	05/19/99	251.89	WG	CVOL	DIBROMOCHLOROMETHANE	ND	0.09	1	µG/L	U
69MW1601A	05/19/99	251.89	WG	CVOL	ETHYLBENZENE	ND	0.096	1	µG/L	U
69MW1601A	05/19/99	251.89	WG	CVOL	METHYL ISOBUTYL KETONE (4-METHYL	ND	0.63	5	µG/L	U
69MW1601A	05/19/99	251.89	WG	CVOL	METHYLENE CHLORIDE	ND	0.9	8.5	µG/L	U
69MW1601A	05/19/99	251.89	WG	CVOL	STYRENE	ND	0.094	1	µG/L	U
69MW1601A	05/19/99	251.89	WG	CVOL	TERT-BUTYL METHYL ETHER	ND	0.1	1	µG/L	U
69MW1601A	05/19/99	251.89	WG	CVOL	TETRACHLOROETHENE(PCE)	ND	0.1	1	µG/L	U
69MW1601A	05/19/99	251.89	WG	CVOL	TOLUENE	ND	0.11	1	µG/L	U

Analysis of Water Samples From New FS-29 Wells

Location	Date	Depth	Matrix	Test	Analyte	Result	DL	RL	Units	Qual
69MW1601A	05/19/99	251.89	WG	CVOL	TRANS-1,2-DICHLOROETHENE	ND	0.12	1	µG/L	U
69MW1601A	05/19/99	251.89	WG	CVOL	TRANS-1,3-DICHLOROPROPENE	ND	0.093	1	µG/L	U
69MW1601A	05/19/99	251.89	WG	CVOL	TRICHLOROETHENE(TCE)	ND	0.12	1	µG/L	U
69MW1601A	05/19/99	251.89	WG	CVOL	VINYL CHLORIDE	ND	0.13	1	µG/L	U
69MW1601A	05/19/99	251.89	WG	CVOL	XYLENES, TOTAL	ND	0.29	1	µG/L	U
69MW1602A	05/11/99	231.9	WG	E504	1,2-DIBROMOETHANE (EDB)	ND	0.005	0.01	µG/L	U
69MW1602A	05/19/99	231.65	WG	E504	1,2-DIBROMO-3-CHLOROPROPANE	ND	0.0031	0.01	µG/L	U
69MW1602A	05/19/99	231.65	WG	E504	1,2-DIBROMOETHANE (EDB)	ND	0.0027	0.01	µG/L	U
69MW1602A	05/19/99	231.65	WG	CVOL	CHLOROFORM	0.53	0.11	1	µG/L	J
69MW1602A	05/19/99	231.65	WG	CVOL	1,1,1-TRICHLOROETHANE	ND	0.094	1	µG/L	U
69MW1602A	05/19/99	231.65	WG	CVOL	1,1,2,2-TETRACHLOROETHANE	ND	0.14	1	µG/L	U
69MW1602A	05/19/99	231.65	WG	CVOL	1,1,2-TRICHLOROETHANE	ND	0.098	1	µG/L	U
69MW1602A	05/19/99	231.65	WG	CVOL	1,1-DICHLOROETHANE	ND	0.13	1	µG/L	U
69MW1602A	05/19/99	231.65	WG	CVOL	1,1-DICHLOROETHENE	ND	0.13	1	µG/L	U
69MW1602A	05/19/99	231.65	WG	CVOL	1,2,4-TRICHLOROBENZENE	ND	0.083	1	µG/L	U
69MW1602A	05/19/99	231.65	WG	CVOL	1,2-DIBROMOETHANE (EDB)	ND	0.16	1	µG/L	U
69MW1602A	05/19/99	231.65	WG	CVOL	1,2-DICHLOROBENZENE	ND	0.12	1	µG/L	U
69MW1602A	05/19/99	231.65	WG	CVOL	1,2-DICHLOROETHANE	ND	0.1	1	µG/L	U
69MW1602A	05/19/99	231.65	WG	CVOL	1,2-DICHLOROPROPANE	ND	0.1	1	µG/L	U
69MW1602A	05/19/99	231.65	WG	CVOL	1,3-DICHLOROBENZENE	ND	0.093	1	µG/L	U
69MW1602A	05/19/99	231.65	WG	CVOL	1,4-DICHLOROBENZENE	ND	0.097	1	µG/L	U
69MW1602A	05/19/99	231.65	WG	CVOL	2-HEXANONE	ND	0.53	5	µG/L	U
69MW1602A	05/19/99	231.65	WG	CVOL	BENZENE	ND	0.099	1	µG/L	U
69MW1602A	05/19/99	231.65	WG	CVOL	BROMOCHLOROMETHANE	ND	0.17	1	µG/L	U
69MW1602A	05/19/99	231.65	WG	CVOL	BROMODICHLOROMETHANE	ND	0.14	1	µG/L	U
69MW1602A	05/19/99	231.65	WG	CVOL	BROMOFORM	ND	0.11	1	µG/L	U
69MW1602A	05/19/99	231.65	WG	CVOL	BROMOMETHANE	ND	0.13	1	µG/L	U
69MW1602A	05/19/99	231.65	WG	CVOL	CARBON DISULFIDE	ND	0.11	1	µG/L	U
69MW1602A	05/19/99	231.65	WG	CVOL	CARBON TETRACHLORIDE	ND	0.1	1	µG/L	U
69MW1602A	05/19/99	231.65	WG	CVOL	CHLOROBENZENE	ND	0.1	1	µG/L	U
69MW1602A	05/19/99	231.65	WG	CVOL	CHLOROETHANE	ND	0.15	1	µG/L	U
69MW1602A	05/19/99	231.65	WG	CVOL	CHLOROMETHANE	ND	0.13	1	µG/L	U
69MW1602A	05/19/99	231.65	WG	CVOL	CIS-1,2-DICHLOROETHENE	ND	0.13	1	µG/L	U
69MW1602A	05/19/99	231.65	WG	CVOL	CIS-1,3-DICHLOROPROPENE	ND	0.12	1	µG/L	U
69MW1602A	05/19/99	231.65	WG	CVOL	DIBROMOCHLOROMETHANE	ND	0.09	1	µG/L	U
69MW1602A	05/19/99	231.65	WG	CVOL	ETHYLBENZENE	ND	0.096	1	µG/L	U
69MW1602A	05/19/99	231.65	WG	CVOL	METHYL ISOBUTYL KETONE (4-METHYL	ND	0.63	5	µG/L	U

Analysis of Water Samples From New FS-29 Wells

Location	Date	Depth	Matrix	Test	Analyte	Result	DL	RL	Units	Qual
69MW1602A	05/19/99	231.65	WG	CVOL	METHYLENE CHLORIDE	ND	0.87	8.5	µG/L	U
69MW1602A	05/19/99	231.65	WG	CVOL	STYRENE	ND	0.094	1	µG/L	U
69MW1602A	05/19/99	231.65	WG	CVOL	TERT-BUTYL METHYL ETHER	ND	0.1	1	µG/L	U
69MW1602A	05/19/99	231.65	WG	CVOL	TETRACHLOROETHENE(PCE)	ND	0.1	1	µG/L	U
69MW1602A	05/19/99	231.65	WG	CVOL	TOLUENE	ND	0.11	1	µG/L	U
69MW1602A	05/19/99	231.65	WG	CVOL	TRANS-1,2-DICHLOROETHENE	ND	0.12	1	µG/L	U
69MW1602A	05/19/99	231.65	WG	CVOL	TRANS-1,3-DICHLOROPROPENE	ND	0.093	1	µG/L	U
69MW1602A	05/19/99	231.65	WG	CVOL	TRICHLOROETHENE(TCE)	ND	0.12	1	µG/L	U
69MW1602A	05/19/99	231.65	WG	CVOL	VINYL CHLORIDE	ND	0.13	1	µG/L	U
69MW1602A	05/19/99	231.65	WG	CVOL	XYLENES, TOTAL	ND	0.29	1	µG/L	U
69MW1603A	05/14/99	240.13	WG	E504	1,2-DIBROMOETHANE (EDB)	ND	0.005	0.01	µG/L	U
69MW1603A	05/19/99	240.39	WG	E504	1,2-DIBROMO-3-CHLOROPROPANE	ND	0.0031	0.01	µG/L	U
69MW1603A	05/19/99	240.39	WG	E504	1,2-DIBROMOETHANE (EDB)	ND	0.0027	0.01	µG/L	U
69MW1603A	05/19/99	240.39	WG	CVOL	1,1,1-TRICHLOROETHANE	ND	0.094	1	µG/L	U
69MW1603A	05/19/99	240.39	WG	CVOL	1,1,2,2-TETRACHLOROETHANE	ND	0.14	1	µG/L	U
69MW1603A	05/19/99	240.39	WG	CVOL	1,1,2-TRICHLOROETHANE	ND	0.098	1	µG/L	U
69MW1603A	05/19/99	240.39	WG	CVOL	1,1-DICHLOROETHANE	ND	0.13	1	µG/L	U
69MW1603A	05/19/99	240.39	WG	CVOL	1,1-DICHLOROETHENE	ND	0.13	1	µG/L	U
69MW1603A	05/19/99	240.39	WG	CVOL	1,2,4-TRICHLOROBENZENE	ND	0.083	1	µG/L	U
69MW1603A	05/19/99	240.39	WG	CVOL	1,2-DIBROMOETHANE (EDB)	ND	0.16	1	µG/L	U
69MW1603A	05/19/99	240.39	WG	CVOL	1,2-DICHLOROBENZENE	ND	0.12	1	µG/L	U
69MW1603A	05/19/99	240.39	WG	CVOL	1,2-DICHLOROETHANE	ND	0.1	1	µG/L	U
69MW1603A	05/19/99	240.39	WG	CVOL	1,2-DICHLOROPROPANE	ND	0.1	1	µG/L	U
69MW1603A	05/19/99	240.39	WG	CVOL	1,3-DICHLOROBENZENE	ND	0.093	1	µG/L	U
69MW1603A	05/19/99	240.39	WG	CVOL	1,4-DICHLOROBENZENE	ND	0.097	1	µG/L	U
69MW1603A	05/19/99	240.39	WG	CVOL	2-HEXANONE	ND	0.53	5	µG/L	U
69MW1603A	05/19/99	240.39	WG	CVOL	BENZENE	ND	0.099	1	µG/L	U
69MW1603A	05/19/99	240.39	WG	CVOL	BROMOCHLOROMETHANE	ND	0.17	1	µG/L	U
69MW1603A	05/19/99	240.39	WG	CVOL	BROMODICHLOROMETHANE	ND	0.14	1	µG/L	U
69MW1603A	05/19/99	240.39	WG	CVOL	BROMOFORM	ND	0.11	1	µG/L	U
69MW1603A	05/19/99	240.39	WG	CVOL	BROMOMETHANE	ND	0.13	1	µG/L	U
69MW1603A	05/19/99	240.39	WG	CVOL	CARBON DISULFIDE	ND	0.11	1	µG/L	U
69MW1603A	05/19/99	240.39	WG	CVOL	CARBON TETRACHLORIDE	ND	0.1	1	µG/L	U
69MW1603A	05/19/99	240.39	WG	CVOL	CHLOROBENZENE	ND	0.1	1	µG/L	U
69MW1603A	05/19/99	240.39	WG	CVOL	CHLOROETHANE	ND	0.15	1	µG/L	U
69MW1603A	05/19/99	240.39	WG	CVOL	CHLOROFORM	ND	0.11	1	µG/L	U
69MW1603A	05/19/99	240.39	WG	CVOL	CHLOROMETHANE	ND	0.13	1	µG/L	U

Analysis of Water Samples From New FS-29 Wells

Location	Date	Depth	Matrix	Test	Analyte	Result	DL	RL	Units	Qual
69MW1603A	05/19/99	240.39	WG	CVOL	CIS-1,2-DICHLOROETHENE	ND	0.13	1	µG/L	U
69MW1603A	05/19/99	240.39	WG	CVOL	CIS-1,3-DICHLOROPROPENE	ND	0.12	1	µG/L	U
69MW1603A	05/19/99	240.39	WG	CVOL	DIBROMOCHLOROMETHANE	ND	0.09	1	µG/L	U
69MW1603A	05/19/99	240.39	WG	CVOL	ETHYLBENZENE	ND	0.096	1	µG/L	U
69MW1603A	05/19/99	240.39	WG	CVOL	METHYL ISOBUTYL KETONE (4-METHYL	ND	0.63	5	µG/L	U
69MW1603A	05/19/99	240.39	WG	CVOL	METHYLENE CHLORIDE	ND	0.85	8.5	µG/L	U
69MW1603A	05/19/99	240.39	WG	CVOL	STYRENE	ND	0.094	1	µG/L	U
69MW1603A	05/19/99	240.39	WG	CVOL	TERT-BUTYL METHYL ETHER	ND	0.1	1	µG/L	U
69MW1603A	05/19/99	240.39	WG	CVOL	TETRACHLOROETHENE(PCE)	ND	0.1	1	µG/L	U
69MW1603A	05/19/99	240.39	WG	CVOL	TOLUENE	ND	0.11	1	µG/L	U
69MW1603A	05/19/99	240.39	WG	CVOL	TRANS-1,2-DICHLOROETHENE	ND	0.12	1	µG/L	U
69MW1603A	05/19/99	240.39	WG	CVOL	TRANS-1,3-DICHLOROPROPENE	ND	0.093	1	µG/L	U
69MW1603A	05/19/99	240.39	WG	CVOL	TRICHLOROETHENE(TCE)	ND	0.12	1	µG/L	U
69MW1603A	05/19/99	240.39	WG	CVOL	VINYL CHLORIDE	ND	0.13	1	µG/L	U
69MW1603A	05/19/99	240.39	WG	CVOL	XYLENES, TOTAL	ND	0.29	1	µG/L	U

Volatile Organic Compound Analysis of Borehole Water Samples From New FS-29 Wells

Location	Date	Depth	Matrix	Test	Analyte	Result	DL	RL	Units	Qual	
69MW1601A	04/01/99	112.5	WA	SW8260	1,1,1-TRICHLOROETHANE	ND	0.328	1	µG/L	U	
69MW1601A	04/01/99	112.5	WA	SW8260	1,1-DICHLOROETHENE	ND	0.532	1	µG/L	U	
69MW1601A	04/01/99	112.5	WA	SW8260	BENZENE	ND	0.371	1	µG/L	U	
69MW1601A	04/01/99	112.5	WA	SW8260	CARBON TETRACHLORIDE	ND	0.222	1	µG/L	U	
69MW1601A	04/01/99	112.5	WA	SW8260	CIS-1,2-DICHLOROETHENE	ND	0.215	1	µG/L	U	
69MW1601A	04/01/99	112.5	WA	SW8260	ETHYLBENZENE	0.496	0.282	1	µG/L	J	
69MW1601A	04/01/99	112.5	WA	SW8260	M,P-XYLENE (SUM OF ISOMERS)	ND	0.406	1	µG/L	U	
69MW1601A	04/01/99	112.5	WA	SW8260	O-XYLENE (1,2-DIMETHYLBENZENE)	ND	0.289	1	µG/L	U	
69MW1601A	04/01/99	112.5	WA	SW8260	TETRACHLOROETHENE(PCE)	ND	0.288	1	µG/L	U	
69MW1601A	04/01/99	112.5	WA	SW8260	TOLUENE	ND	0.197	1	µG/L	U	
69MW1601A	04/01/99	112.5	WA	SW8260	TRANS-1,2-DICHLOROETHENE	ND	0.168	1	µG/L	U	
69MW1601A	04/01/99	112.5	WA	SW8260	TRICHLOROETHENE(TCE)	ND	0.322	1	µG/L	U	
69MW1601A	04/01/99	122.5	WA	SW8260	1,1,1-TRICHLOROETHANE	ND	0.328	1	µG/L	U	
69MW1601A	04/01/99	122.5	WA	SW8260	1,1-DICHLOROETHENE	ND	0.532	1	µG/L	U	
69MW1601A	04/01/99	122.5	WA	SW8260	BENZENE	ND	0.371	1	µG/L	U	
69MW1601A	04/01/99	122.5	WA	SW8260	CARBON TETRACHLORIDE	ND	0.222	1	µG/L	U	
69MW1601A	04/01/99	122.5	WA	SW8260	CIS-1,2-DICHLOROETHENE	ND	0.215	1	µG/L	U	
69MW1601A	04/01/99	122.5	WA	SW8260	ETHYLBENZENE	0.359	0.282	1	µG/L	J	
69MW1601A	04/01/99	122.5	WA	SW8260	M,P-XYLENE (SUM OF ISOMERS)	ND	0.406	1	µG/L	U	
69MW1601A	04/01/99	122.5	WA	SW8260	O-XYLENE (1,2-DIMETHYLBENZENE)	ND	0.289	1	µG/L	U	
69MW1601A	04/01/99	122.5	WA	SW8260	TETRACHLOROETHENE(PCE)	ND	0.288	1	µG/L	U	
69MW1601A	04/01/99	122.5	WA	SW8260	TOLUENE	ND	0.197	1	µG/L	U	
69MW1601A	04/01/99	122.5	WA	SW8260	TRANS-1,2-DICHLOROETHENE	ND	0.168	1	µG/L	U	
69MW1601A	04/01/99	122.5	WA	SW8260	TRICHLOROETHENE(TCE)	ND	0.322	1	µG/L	U	
69MW1601A	04/01/99	132.5	WA	SW8260	1,1,1-TRICHLOROETHANE	1.47	0.328	1	µG/L		
69MW1601A	04/01/99	132.5	WA	SW8260	1,1-DICHLOROETHENE	ND	0.532	1	µG/L	U	
69MW1601A	04/01/99	132.5	WA	SW8260	BENZENE	ND	0.371	1	µG/L	U	
69MW1601A	04/01/99	132.5	WA	SW8260	CARBON TETRACHLORIDE	ND	0.222	1	µG/L	U	
69MW1601A	04/01/99	132.5	WA	SW8260	CIS-1,2-DICHLOROETHENE	ND	0.215	1	µG/L	U	
69MW1601A	04/01/99	132.5	WA	SW8260	ETHYLBENZENE	0.581	0.282	1	µG/L	J	
69MW1601A	04/01/99	132.5	WA	SW8260	M,P-XYLENE (SUM OF ISOMERS)	ND	0.406	1	µG/L	U	
69MW1601A	04/01/99	132.5	WA	SW8260	O-XYLENE (1,2-DIMETHYLBENZENE)	ND	0.289	1	µG/L	U	
69MW1601A	04/01/99	132.5	WA	SW8260	TETRACHLOROETHENE(PCE)	ND	0.288	1	µG/L	U	
69MW1601A	04/01/99	132.5	WA	SW8260	TOLUENE	ND	0.197	1	µG/L	U	
69MW1601A	04/01/99	132.5	WA	SW8260	TRANS-1,2-DICHLOROETHENE	ND	0.168	1	µG/L	U	
69MW1601A	04/01/99	132.5	WA	SW8260	TRICHLOROETHENE(TCE)	ND	0.322	1	µG/L	U	
69MW1601A	04/01/99	142.5	WA	SW8260	1,1,1-TRICHLOROETHANE	ND	0.328	1	µG/L	U	
69MW1601A	04/01/99	142.5	WA	SW8260	1,1-DICHLOROETHENE	ND	0.532	1	µG/L	U	
69MW1601A	04/01/99	142.5	WA	SW8260	BENZENE	ND	0.371	1	µG/L	U	

Volatile Organic Compound Analysis of Borehole Water Samples From New FS-29 Wells

Location	Date	Depth	Matrix	Test	Analyte	Result	DL	RL	Units	Qual	
69MW1601A	04/01/99	142.5	WA	SW8260	CARBON TETRACHLORIDE	ND	0.222	1	µG/L	U	
69MW1601A	04/01/99	142.5	WA	SW8260	CIS-1,2-DICHLOROETHENE	ND	0.215	1	µG/L	U	
69MW1601A	04/01/99	142.5	WA	SW8260	ETHYLBENZENE	0.484	0.282	1	µG/L	J	
69MW1601A	04/01/99	142.5	WA	SW8260	M,P-XYLENE (SUM OF ISOMERS)	ND	0.406	1	µG/L	U	
69MW1601A	04/01/99	142.5	WA	SW8260	O-XYLENE (1,2-DIMETHYLBENZENE)	ND	0.289	1	µG/L	U	
69MW1601A	04/01/99	142.5	WA	SW8260	TETRACHLOROETHENE(PCE)	ND	0.288	1	µG/L	U	
69MW1601A	04/01/99	142.5	WA	SW8260	TOLUENE	ND	0.197	1	µG/L	U	
69MW1601A	04/01/99	142.5	WA	SW8260	TRANS-1,2-DICHLOROETHENE	ND	0.168	1	µG/L	U	
69MW1601A	04/01/99	142.5	WA	SW8260	TRICHLOROETHENE(TCE)	ND	0.322	1	µG/L	U	
69MW1601A	04/01/99	152.5	WA	SW8260	1,1,1-TRICHLOROETHANE	ND	0.328	1	µG/L	U	
69MW1601A	04/01/99	152.5	WA	SW8260	1,1-DICHLOROETHENE	ND	0.532	1	µG/L	U	
69MW1601A	04/01/99	152.5	WA	SW8260	BENZENE	ND	0.371	1	µG/L	U	
69MW1601A	04/01/99	152.5	WA	SW8260	CARBON TETRACHLORIDE	ND	0.222	1	µG/L	U	
69MW1601A	04/01/99	152.5	WA	SW8260	CIS-1,2-DICHLOROETHENE	ND	0.215	1	µG/L	U	
69MW1601A	04/01/99	152.5	WA	SW8260	ETHYLBENZENE	0.483	0.282	1	µG/L	J	
69MW1601A	04/01/99	152.5	WA	SW8260	M,P-XYLENE (SUM OF ISOMERS)	ND	0.406	1	µG/L	U	
69MW1601A	04/01/99	152.5	WA	SW8260	O-XYLENE (1,2-DIMETHYLBENZENE)	ND	0.289	1	µG/L	U	
69MW1601A	04/01/99	152.5	WA	SW8260	TETRACHLOROETHENE(PCE)	ND	0.288	1	µG/L	U	
69MW1601A	04/01/99	152.5	WA	SW8260	TOLUENE	ND	0.197	1	µG/L	U	
69MW1601A	04/01/99	152.5	WA	SW8260	TRANS-1,2-DICHLOROETHENE	ND	0.168	1	µG/L	U	
69MW1601A	04/01/99	152.5	WA	SW8260	TRICHLOROETHENE(TCE)	ND	0.322	1	µG/L	U	
69MW1601A	04/01/99	162.5	WA	SW8260	1,1,1-TRICHLOROETHANE	ND	0.328	1	µG/L	U	
69MW1601A	04/01/99	162.5	WA	SW8260	1,1-DICHLOROETHENE	ND	0.532	1	µG/L	U	
69MW1601A	04/01/99	162.5	WA	SW8260	BENZENE	ND	0.371	1	µG/L	U	
69MW1601A	04/01/99	162.5	WA	SW8260	CARBON TETRACHLORIDE	ND	0.222	1	µG/L	U	
69MW1601A	04/01/99	162.5	WA	SW8260	CIS-1,2-DICHLOROETHENE	ND	0.215	1	µG/L	U	
69MW1601A	04/01/99	162.5	WA	SW8260	ETHYLBENZENE	0.525	0.282	1	µG/L	J	
69MW1601A	04/01/99	162.5	WA	SW8260	M,P-XYLENE (SUM OF ISOMERS)	ND	0.406	1	µG/L	U	
69MW1601A	04/01/99	162.5	WA	SW8260	O-XYLENE (1,2-DIMETHYLBENZENE)	ND	0.289	1	µG/L	U	
69MW1601A	04/01/99	162.5	WA	SW8260	TETRACHLOROETHENE(PCE)	ND	0.288	1	µG/L	U	
69MW1601A	04/01/99	162.5	WA	SW8260	TOLUENE	ND	0.197	1	µG/L	U	
69MW1601A	04/01/99	162.5	WA	SW8260	TRANS-1,2-DICHLOROETHENE	ND	0.168	1	µG/L	U	
69MW1601A	04/01/99	162.5	WA	SW8260	TRICHLOROETHENE(TCE)	ND	0.322	1	µG/L	U	
69MW1601A	04/01/99	172.5	WA	SW8260	1,1,1-TRICHLOROETHANE	ND	0.328	1	µG/L	U	
69MW1601A	04/01/99	172.5	WA	SW8260	1,1-DICHLOROETHENE	ND	0.532	1	µG/L	U	
69MW1601A	04/01/99	172.5	WA	SW8260	BENZENE	ND	0.371	1	µG/L	U	
69MW1601A	04/01/99	172.5	WA	SW8260	CARBON TETRACHLORIDE	ND	0.222	1	µG/L	U	
69MW1601A	04/01/99	172.5	WA	SW8260	CIS-1,2-DICHLOROETHENE	ND	0.215	1	µG/L	U	
69MW1601A	04/01/99	172.5	WA	SW8260	ETHYLBENZENE	ND	0.282	1	µG/L	U	

Volatile Organic Compound Analysis of Borehole Water Samples From New FS-29 Wells

Location	Date	Depth	Matrix	Test	Analyte	Result	DL	RL	Units	Qual	
69MW1601A	04/01/99	172.5	WA	SW8260	M,P-XYLENE (SUM OF ISOMERS)	ND	0.406	1	µG/L	U	
69MW1601A	04/01/99	172.5	WA	SW8260	O-XYLENE (1,2-DIMETHYLBENZENE)	ND	0.289	1	µG/L	U	
69MW1601A	04/01/99	172.5	WA	SW8260	TETRACHLOROETHENE(PCE)	ND	0.288	1	µG/L	U	
69MW1601A	04/01/99	172.5	WA	SW8260	TOLUENE	ND	0.197	1	µG/L	U	
69MW1601A	04/01/99	172.5	WA	SW8260	TRANS-1,2-DICHLOROETHENE	ND	0.168	1	µG/L	U	
69MW1601A	04/01/99	172.5	WA	SW8260	TRICHLOROETHENE(TCE)	ND	0.322	1	µG/L	U	
69MW1601A	04/01/99	182.5	WA	SW8260	1,1,1-TRICHLOROETHANE	ND	0.328	1	µG/L	U	
69MW1601A	04/01/99	182.5	WA	SW8260	1,1-DICHLOROETHENE	ND	0.532	1	µG/L	U	
69MW1601A	04/01/99	182.5	WA	SW8260	BENZENE	ND	0.371	1	µG/L	U	
69MW1601A	04/01/99	182.5	WA	SW8260	CARBON TETRACHLORIDE	ND	0.222	1	µG/L	U	
69MW1601A	04/01/99	182.5	WA	SW8260	CIS-1,2-DICHLOROETHENE	ND	0.215	1	µG/L	U	
69MW1601A	04/01/99	182.5	WA	SW8260	ETHYLBENZENE	ND	0.282	1	µG/L	U	
69MW1601A	04/01/99	182.5	WA	SW8260	M,P-XYLENE (SUM OF ISOMERS)	ND	0.406	1	µG/L	U	
69MW1601A	04/01/99	182.5	WA	SW8260	O-XYLENE (1,2-DIMETHYLBENZENE)	ND	0.289	1	µG/L	U	
69MW1601A	04/01/99	182.5	WA	SW8260	TETRACHLOROETHENE(PCE)	ND	0.288	1	µG/L	U	
69MW1601A	04/01/99	182.5	WA	SW8260	TOLUENE	ND	0.197	1	µG/L	U	
69MW1601A	04/01/99	182.5	WA	SW8260	TRANS-1,2-DICHLOROETHENE	ND	0.168	1	µG/L	U	
69MW1601A	04/01/99	182.5	WA	SW8260	TRICHLOROETHENE(TCE)	ND	0.322	1	µG/L	U	
69MW1601A	04/01/99	192.5	WA	SW8260	1,1,1-TRICHLOROETHANE	ND	0.328	1	µG/L	U	
69MW1601A	04/01/99	192.5	WA	SW8260	1,1-DICHLOROETHENE	ND	0.532	1	µG/L	U	
69MW1601A	04/01/99	192.5	WA	SW8260	BENZENE	ND	0.371	1	µG/L	U	
69MW1601A	04/01/99	192.5	WA	SW8260	CARBON TETRACHLORIDE	ND	0.222	1	µG/L	U	
69MW1601A	04/01/99	192.5	WA	SW8260	CIS-1,2-DICHLOROETHENE	ND	0.215	1	µG/L	U	
69MW1601A	04/01/99	192.5	WA	SW8260	ETHYLBENZENE	ND	0.282	1	µG/L	U	
69MW1601A	04/01/99	192.5	WA	SW8260	M,P-XYLENE (SUM OF ISOMERS)	ND	0.406	1	µG/L	U	
69MW1601A	04/01/99	192.5	WA	SW8260	O-XYLENE (1,2-DIMETHYLBENZENE)	ND	0.289	1	µG/L	U	
69MW1601A	04/01/99	192.5	WA	SW8260	TETRACHLOROETHENE(PCE)	ND	0.288	1	µG/L	U	
69MW1601A	04/01/99	192.5	WA	SW8260	TOLUENE	ND	0.197	1	µG/L	U	
69MW1601A	04/01/99	192.5	WA	SW8260	TRANS-1,2-DICHLOROETHENE	ND	0.168	1	µG/L	U	
69MW1601A	04/01/99	192.5	WA	SW8260	TRICHLOROETHENE(TCE)	ND	0.322	1	µG/L	U	
69MW1601A	04/02/99	202.5	WA	SW8260	1,1,1-TRICHLOROETHANE	ND	0.328	1	µG/L	U	
69MW1601A	04/02/99	202.5	WA	SW8260	1,1-DICHLOROETHENE	ND	0.532	1	µG/L	U	
69MW1601A	04/02/99	202.5	WA	SW8260	BENZENE	ND	0.371	1	µG/L	U	
69MW1601A	04/02/99	202.5	WA	SW8260	CARBON TETRACHLORIDE	ND	0.222	1	µG/L	U	
69MW1601A	04/02/99	202.5	WA	SW8260	CIS-1,2-DICHLOROETHENE	ND	0.215	1	µG/L	U	
69MW1601A	04/02/99	202.5	WA	SW8260	ETHYLBENZENE	ND	0.282	1	µG/L	U	
69MW1601A	04/02/99	202.5	WA	SW8260	M,P-XYLENE (SUM OF ISOMERS)	ND	0.406	1	µG/L	U	
69MW1601A	04/02/99	202.5	WA	SW8260	O-XYLENE (1,2-DIMETHYLBENZENE)	ND	0.289	1	µG/L	U	
69MW1601A	04/02/99	202.5	WA	SW8260	TETRACHLOROETHENE(PCE)	ND	0.288	1	µG/L	U	

Volatile Organic Compound Analysis of Borehole Water Samples From New FS-29 Wells

Location	Date	Depth	Matrix	Test	Analyte	Result	DL	RL	Units	Qual	
69MW1601A	04/02/99	202.5	WA	SW8260	TOLUENE	ND	0.197	1	µG/L	U	
69MW1601A	04/02/99	202.5	WA	SW8260	TRANS-1,2-DICHLOROETHENE	ND	0.168	1	µG/L	U	
69MW1601A	04/02/99	202.5	WA	SW8260	TRICHLOROETHENE(TCE)	ND	0.322	1	µG/L	U	
69MW1601A	04/02/99	212.5	WA	SW8260	1,1,1-TRICHLOROETHANE	ND	0.328	1	µG/L	U	
69MW1601A	04/02/99	212.5	WA	SW8260	1,1-DICHLOROETHENE	ND	0.532	1	µG/L	U	
69MW1601A	04/02/99	212.5	WA	SW8260	BENZENE	ND	0.371	1	µG/L	U	
69MW1601A	04/02/99	212.5	WA	SW8260	CARBON TETRACHLORIDE	ND	0.222	1	µG/L	U	
69MW1601A	04/02/99	212.5	WA	SW8260	CIS-1,2-DICHLOROETHENE	ND	0.215	1	µG/L	U	
69MW1601A	04/02/99	212.5	WA	SW8260	ETHYLBENZENE	ND	0.282	1	µG/L	U	
69MW1601A	04/02/99	212.5	WA	SW8260	M,P-XYLENE (SUM OF ISOMERS)	ND	0.406	1	µG/L	U	
69MW1601A	04/02/99	212.5	WA	SW8260	O-XYLENE (1,2-DIMETHYLBENZENE)	ND	0.289	1	µG/L	U	
69MW1601A	04/02/99	212.5	WA	SW8260	TETRACHLOROETHENE(PCE)	ND	0.288	1	µG/L	U	
69MW1601A	04/02/99	212.5	WA	SW8260	TOLUENE	ND	0.197	1	µG/L	U	
69MW1601A	04/02/99	212.5	WA	SW8260	TRANS-1,2-DICHLOROETHENE	ND	0.168	1	µG/L	U	
69MW1601A	04/02/99	212.5	WA	SW8260	TRICHLOROETHENE(TCE)	ND	0.322	1	µG/L	U	
69MW1601A	04/02/99	222.5	WA	SW8260	1,1,1-TRICHLOROETHANE	ND	0.328	1	µG/L	U	
69MW1601A	04/02/99	222.5	WA	SW8260	1,1-DICHLOROETHENE	ND	0.532	1	µG/L	U	
69MW1601A	04/02/99	222.5	WA	SW8260	BENZENE	ND	0.371	1	µG/L	U	
69MW1601A	04/02/99	222.5	WA	SW8260	CARBON TETRACHLORIDE	ND	0.222	1	µG/L	U	
69MW1601A	04/02/99	222.5	WA	SW8260	CIS-1,2-DICHLOROETHENE	ND	0.215	1	µG/L	U	
69MW1601A	04/02/99	222.5	WA	SW8260	ETHYLBENZENE	ND	0.282	1	µG/L	U	
69MW1601A	04/02/99	222.5	WA	SW8260	M,P-XYLENE (SUM OF ISOMERS)	ND	0.406	1	µG/L	U	
69MW1601A	04/02/99	222.5	WA	SW8260	O-XYLENE (1,2-DIMETHYLBENZENE)	ND	0.289	1	µG/L	U	
69MW1601A	04/02/99	222.5	WA	SW8260	TETRACHLOROETHENE(PCE)	ND	0.288	1	µG/L	U	
69MW1601A	04/02/99	222.5	WA	SW8260	TOLUENE	ND	0.197	1	µG/L	U	
69MW1601A	04/02/99	222.5	WA	SW8260	TRANS-1,2-DICHLOROETHENE	ND	0.168	1	µG/L	U	
69MW1601A	04/02/99	222.5	WA	SW8260	TRICHLOROETHENE(TCE)	ND	0.322	1	µG/L	U	
69MW1601A	04/02/99	232.5	WA	SW8260	1,1,1-TRICHLOROETHANE	ND	0.328	1	µG/L	U	
69MW1601A	04/02/99	232.5	WA	SW8260	1,1,1-TRICHLOROETHANE	ND	0.328	1	µG/L	U	duplicate
69MW1601A	04/02/99	232.5	WA	SW8260	1,1-DICHLOROETHENE	ND	0.532	1	µG/L	U	
69MW1601A	04/02/99	232.5	WA	SW8260	1,1-DICHLOROETHENE	ND	0.532	1	µG/L	U	duplicate
69MW1601A	04/02/99	232.5	WA	SW8260	BENZENE	ND	0.371	1	µG/L	U	
69MW1601A	04/02/99	232.5	WA	SW8260	BENZENE	ND	0.371	1	µG/L	U	duplicate
69MW1601A	04/02/99	232.5	WA	SW8260	CARBON TETRACHLORIDE	ND	0.222	1	µG/L	U	
69MW1601A	04/02/99	232.5	WA	SW8260	CARBON TETRACHLORIDE	ND	0.222	1	µG/L	U	duplicate
69MW1601A	04/02/99	232.5	WA	SW8260	CIS-1,2-DICHLOROETHENE	ND	0.215	1	µG/L	U	
69MW1601A	04/02/99	232.5	WA	SW8260	CIS-1,2-DICHLOROETHENE	ND	0.215	1	µG/L	U	duplicate
69MW1601A	04/02/99	232.5	WA	SW8260	ETHYLBENZENE	ND	0.282	1	µG/L	U	
69MW1601A	04/02/99	232.5	WA	SW8260	ETHYLBENZENE	ND	0.282	1	µG/L	U	duplicate



Volatile Organic Compound Analysis of Borehole Water Samples From New FS-29 Wells

Location	Date	Depth	Matrix	Test	Analyte	Result	DL	RL	Units	Qual	
69MW1601A	04/02/99	232.5	WA	SW8260	M,P-XYLENE (SUM OF ISOMERS)	ND	0.406	1	µG/L	U	
69MW1601A	04/02/99	232.5	WA	SW8260	M,P-XYLENE (SUM OF ISOMERS)	ND	0.406	1	µG/L	U	duplicate
69MW1601A	04/02/99	232.5	WA	SW8260	O-XYLENE (1,2-DIMETHYLBENZENE)	ND	0.289	1	µG/L	U	
69MW1601A	04/02/99	232.5	WA	SW8260	O-XYLENE (1,2-DIMETHYLBENZENE)	ND	0.289	1	µG/L	U	duplicate
69MW1601A	04/02/99	232.5	WA	SW8260	TETRACHLOROETHENE(PCE)	ND	0.288	1	µG/L	U	
69MW1601A	04/02/99	232.5	WA	SW8260	TETRACHLOROETHENE(PCE)	ND	0.288	1	µG/L	U	duplicate
69MW1601A	04/02/99	232.5	WA	SW8260	TOLUENE	ND	0.197	1	µG/L	U	
69MW1601A	04/02/99	232.5	WA	SW8260	TOLUENE	ND	0.197	1	µG/L	U	duplicate
69MW1601A	04/02/99	232.5	WA	SW8260	TRANS-1,2-DICHLOROETHENE	ND	0.168	1	µG/L	U	
69MW1601A	04/02/99	232.5	WA	SW8260	TRANS-1,2-DICHLOROETHENE	ND	0.168	1	µG/L	U	duplicate
69MW1601A	04/02/99	232.5	WA	SW8260	TRICHLOROETHENE(TCE)	ND	0.322	1	µG/L	U	
69MW1601A	04/02/99	232.5	WA	SW8260	TRICHLOROETHENE(TCE)	ND	0.322	1	µG/L	U	duplicate
69MW1601A	04/02/99	242.5	WA	SW8260	1,1,1-TRICHLOROETHANE	ND	0.328	1	µG/L	U	
69MW1601A	04/02/99	242.5	WA	SW8260	1,1-DICHLOROETHENE	ND	0.532	1	µG/L	U	
69MW1601A	04/02/99	242.5	WA	SW8260	BENZENE	ND	0.371	1	µG/L	U	
69MW1601A	04/02/99	242.5	WA	SW8260	CARBON TETRACHLORIDE	ND	0.222	1	µG/L	U	
69MW1601A	04/02/99	242.5	WA	SW8260	CIS-1,2-DICHLOROETHENE	ND	0.215	1	µG/L	U	
69MW1601A	04/02/99	242.5	WA	SW8260	ETHYLBENZENE	ND	0.282	1	µG/L	U	
69MW1601A	04/02/99	242.5	WA	SW8260	M,P-XYLENE (SUM OF ISOMERS)	ND	0.406	1	µG/L	U	
69MW1601A	04/02/99	242.5	WA	SW8260	O-XYLENE (1,2-DIMETHYLBENZENE)	ND	0.289	1	µG/L	U	
69MW1601A	04/02/99	242.5	WA	SW8260	TETRACHLOROETHENE(PCE)	ND	0.288	1	µG/L	U	
69MW1601A	04/02/99	242.5	WA	SW8260	TOLUENE	ND	0.197	1	µG/L	U	
69MW1601A	04/02/99	242.5	WA	SW8260	TRANS-1,2-DICHLOROETHENE	ND	0.168	1	µG/L	U	
69MW1601A	04/02/99	242.5	WA	SW8260	TRICHLOROETHENE(TCE)	ND	0.322	1	µG/L	U	
69MW1601A	04/06/99	252.5	WA	SW8260	1,1,1-TRICHLOROETHANE	ND	0.328	1	µG/L	U	
69MW1601A	04/06/99	252.5	WA	SW8260	1,1-DICHLOROETHENE	ND	0.532	1	µG/L	U	
69MW1601A	04/06/99	252.5	WA	SW8260	BENZENE	ND	0.371	1	µG/L	U	
69MW1601A	04/06/99	252.5	WA	SW8260	CARBON TETRACHLORIDE	ND	0.222	1	µG/L	U	
69MW1601A	04/06/99	252.5	WA	SW8260	CIS-1,2-DICHLOROETHENE	ND	0.215	1	µG/L	U	
69MW1601A	04/06/99	252.5	WA	SW8260	ETHYLBENZENE	ND	0.282	1	µG/L	U	
69MW1601A	04/06/99	252.5	WA	SW8260	M,P-XYLENE (SUM OF ISOMERS)	ND	0.406	1	µG/L	U	
69MW1601A	04/06/99	252.5	WA	SW8260	O-XYLENE (1,2-DIMETHYLBENZENE)	ND	0.289	1	µG/L	U	
69MW1601A	04/06/99	252.5	WA	SW8260	TETRACHLOROETHENE(PCE)	ND	0.288	1	µG/L	U	
69MW1601A	04/06/99	252.5	WA	SW8260	TOLUENE	ND	0.197	1	µG/L	U	
69MW1601A	04/06/99	252.5	WA	SW8260	TRANS-1,2-DICHLOROETHENE	ND	0.168	1	µG/L	U	
69MW1601A	04/06/99	252.5	WA	SW8260	TRICHLOROETHENE(TCE)	ND	0.322	1	µG/L	U	
69MW1601A	04/06/99	262.5	WA	SW8260	1,1,1-TRICHLOROETHANE	ND	0.328	1	µG/L	U	
69MW1601A	04/06/99	262.5	WA	SW8260	1,1-DICHLOROETHENE	ND	0.532	1	µG/L	U	
69MW1601A	04/06/99	262.5	WA	SW8260	BENZENE	ND	0.371	1	µG/L	U	

Volatile Organic Compound Analysis of Borehole Water Samples From New FS-29 Wells

Location	Date	Depth	Matrix	Test	Analyte	Result	DL	RL	Units	Qual	
69MW1601A	04/06/99	262.5	WA	SW8260	CARBON TETRACHLORIDE	ND	0.222	1	µG/L	U	
69MW1601A	04/06/99	262.5	WA	SW8260	CIS-1,2-DICHLOROETHENE	ND	0.215	1	µG/L	U	
69MW1601A	04/06/99	262.5	WA	SW8260	ETHYLBENZENE	ND	0.282	1	µG/L	U	
69MW1601A	04/06/99	262.5	WA	SW8260	M,P-XYLENE (SUM OF ISOMERS)	ND	0.406	1	µG/L	U	
69MW1601A	04/06/99	262.5	WA	SW8260	O-XYLENE (1,2-DIMETHYLBENZENE)	ND	0.289	1	µG/L	U	
69MW1601A	04/06/99	262.5	WA	SW8260	TETRACHLOROETHENE(PCE)	ND	0.288	1	µG/L	U	
69MW1601A	04/06/99	262.5	WA	SW8260	TOLUENE	ND	0.197	1	µG/L	U	
69MW1601A	04/06/99	262.5	WA	SW8260	TRANS-1,2-DICHLOROETHENE	ND	0.168	1	µG/L	U	
69MW1601A	04/06/99	262.5	WA	SW8260	TRICHLOROETHENE(TCE)	ND	0.322	1	µG/L	U	
69MW1601A	04/06/99	272.5	WA	SW8260	1,1,1-TRICHLOROETHANE	ND	0.328	1	µG/L	U	
69MW1601A	04/06/99	272.5	WA	SW8260	1,1-DICHLOROETHENE	ND	0.532	1	µG/L	U	
69MW1601A	04/06/99	272.5	WA	SW8260	BENZENE	ND	0.371	1	µG/L	U	
69MW1601A	04/06/99	272.5	WA	SW8260	CARBON TETRACHLORIDE	ND	0.222	1	µG/L	U	
69MW1601A	04/06/99	272.5	WA	SW8260	CIS-1,2-DICHLOROETHENE	ND	0.215	1	µG/L	U	
69MW1601A	04/06/99	272.5	WA	SW8260	ETHYLBENZENE	ND	0.282	1	µG/L	U	
69MW1601A	04/06/99	272.5	WA	SW8260	M,P-XYLENE (SUM OF ISOMERS)	ND	0.406	1	µG/L	U	
69MW1601A	04/06/99	272.5	WA	SW8260	O-XYLENE (1,2-DIMETHYLBENZENE)	ND	0.289	1	µG/L	U	
69MW1601A	04/06/99	272.5	WA	SW8260	TETRACHLOROETHENE(PCE)	ND	0.288	1	µG/L	U	
69MW1601A	04/06/99	272.5	WA	SW8260	TOLUENE	ND	0.197	1	µG/L	U	
69MW1601A	04/06/99	272.5	WA	SW8260	TRANS-1,2-DICHLOROETHENE	ND	0.168	1	µG/L	U	
69MW1601A	04/06/99	272.5	WA	SW8260	TRICHLOROETHENE(TCE)	ND	0.322	1	µG/L	U	
69MW1602A	04/09/99	82.5	WA	SW8260	1,1,1-TRICHLOROETHANE	ND	0.328	1	µG/L	U	
69MW1602A	04/09/99	82.5	WA	SW8260	1,1-DICHLOROETHENE	ND	0.532	1	µG/L	U	
69MW1602A	04/09/99	82.5	WA	SW8260	BENZENE	ND	0.371	1	µG/L	U	
69MW1602A	04/09/99	82.5	WA	SW8260	CARBON TETRACHLORIDE	ND	0.222	1	µG/L	U	
69MW1602A	04/09/99	82.5	WA	SW8260	CIS-1,2-DICHLOROETHENE	ND	0.215	1	µG/L	U	
69MW1602A	04/09/99	82.5	WA	SW8260	ETHYLBENZENE	ND	0.282	1	µG/L	U	
69MW1602A	04/09/99	82.5	WA	SW8260	M,P-XYLENE (SUM OF ISOMERS)	ND	0.406	1	µG/L	U	
69MW1602A	04/09/99	82.5	WA	SW8260	O-XYLENE (1,2-DIMETHYLBENZENE)	ND	0.289	1	µG/L	U	
69MW1602A	04/09/99	82.5	WA	SW8260	TETRACHLOROETHENE(PCE)	ND	0.288	1	µG/L	U	
69MW1602A	04/09/99	82.5	WA	SW8260	TOLUENE	ND	0.197	1	µG/L	U	
69MW1602A	04/09/99	82.5	WA	SW8260	TRANS-1,2-DICHLOROETHENE	ND	0.168	1	µG/L	U	
69MW1602A	04/09/99	82.5	WA	SW8260	TRICHLOROETHENE(TCE)	ND	0.322	1	µG/L	U	
69MW1602A	04/09/99	92.5	WA	SW8260	1,1,1-TRICHLOROETHANE	ND	0.328	1	µG/L	U	
69MW1602A	04/09/99	92.5	WA	SW8260	1,1-DICHLOROETHENE	ND	0.532	1	µG/L	U	
69MW1602A	04/09/99	92.5	WA	SW8260	BENZENE	ND	0.371	1	µG/L	U	
69MW1602A	04/09/99	92.5	WA	SW8260	CARBON TETRACHLORIDE	ND	0.222	1	µG/L	U	
69MW1602A	04/09/99	92.5	WA	SW8260	CIS-1,2-DICHLOROETHENE	ND	0.215	1	µG/L	U	
69MW1602A	04/09/99	92.5	WA	SW8260	ETHYLBENZENE	ND	0.282	1	µG/L	U	

Volatile Organic Compound Analysis of Borehole Water Samples From New FS-29 Wells

Location	Date	Depth	Matrix	Test	Analyte	Result	DL	RL	Units	Qual	
69MW1602A	04/09/99	92.5	WA	SW8260	M,P-XYLENE (SUM OF ISOMERS)	ND	0.406	1	µG/L	U	
69MW1602A	04/09/99	92.5	WA	SW8260	O-XYLENE (1,2-DIMETHYLBENZENE)	ND	0.289	1	µG/L	U	
69MW1602A	04/09/99	92.5	WA	SW8260	TETRACHLOROETHENE(PCE)	ND	0.288	1	µG/L	U	
69MW1602A	04/09/99	92.5	WA	SW8260	TOLUENE	ND	0.197	1	µG/L	U	
69MW1602A	04/09/99	92.5	WA	SW8260	TRANS-1,2-DICHLOROETHENE	ND	0.168	1	µG/L	U	
69MW1602A	04/09/99	92.5	WA	SW8260	TRICHLOROETHENE(TCE)	ND	0.322	1	µG/L	U	
69MW1602A	04/09/99	102.5	WA	SW8260	1,1,1-TRICHLOROETHANE	ND	0.328	1	µG/L	U	
69MW1602A	04/09/99	102.5	WA	SW8260	1,1,1-TRICHLOROETHANE	ND	0.328	1	µG/L	U	duplicate
69MW1602A	04/09/99	102.5	WA	SW8260	1,1-DICHLOROETHENE	ND	0.532	1	µG/L	U	
69MW1602A	04/09/99	102.5	WA	SW8260	1,1-DICHLOROETHENE	ND	0.532	1	µG/L	U	duplicate
69MW1602A	04/09/99	102.5	WA	SW8260	BENZENE	ND	0.371	1	µG/L	U	
69MW1602A	04/09/99	102.5	WA	SW8260	BENZENE	ND	0.371	1	µG/L	U	duplicate
69MW1602A	04/09/99	102.5	WA	SW8260	CARBON TETRACHLORIDE	ND	0.222	1	µG/L	U	
69MW1602A	04/09/99	102.5	WA	SW8260	CARBON TETRACHLORIDE	ND	0.222	1	µG/L	U	duplicate
69MW1602A	04/09/99	102.5	WA	SW8260	CIS-1,2-DICHLOROETHENE	ND	0.215	1	µG/L	U	
69MW1602A	04/09/99	102.5	WA	SW8260	CIS-1,2-DICHLOROETHENE	ND	0.215	1	µG/L	U	duplicate
69MW1602A	04/09/99	102.5	WA	SW8260	ETHYLBENZENE	ND	0.282	1	µG/L	U	
69MW1602A	04/09/99	102.5	WA	SW8260	ETHYLBENZENE	ND	0.282	1	µG/L	U	duplicate
69MW1602A	04/09/99	102.5	WA	SW8260	M,P-XYLENE (SUM OF ISOMERS)	ND	0.406	1	µG/L	U	
69MW1602A	04/09/99	102.5	WA	SW8260	M,P-XYLENE (SUM OF ISOMERS)	ND	0.406	1	µG/L	U	duplicate
69MW1602A	04/09/99	102.5	WA	SW8260	O-XYLENE (1,2-DIMETHYLBENZENE)	ND	0.289	1	µG/L	U	
69MW1602A	04/09/99	102.5	WA	SW8260	O-XYLENE (1,2-DIMETHYLBENZENE)	ND	0.289	1	µG/L	U	duplicate
69MW1602A	04/09/99	102.5	WA	SW8260	TETRACHLOROETHENE(PCE)	ND	0.288	1	µG/L	U	
69MW1602A	04/09/99	102.5	WA	SW8260	TETRACHLOROETHENE(PCE)	ND	0.288	1	µG/L	U	duplicate
69MW1602A	04/09/99	102.5	WA	SW8260	TOLUENE	ND	0.197	1	µG/L	U	
69MW1602A	04/09/99	102.5	WA	SW8260	TOLUENE	ND	0.197	1	µG/L	U	duplicate
69MW1602A	04/09/99	102.5	WA	SW8260	TRANS-1,2-DICHLOROETHENE	ND	0.168	1	µG/L	U	
69MW1602A	04/09/99	102.5	WA	SW8260	TRANS-1,2-DICHLOROETHENE	ND	0.168	1	µG/L	U	duplicate
69MW1602A	04/09/99	102.5	WA	SW8260	TRICHLOROETHENE(TCE)	ND	0.322	1	µG/L	U	
69MW1602A	04/09/99	102.5	WA	SW8260	TRICHLOROETHENE(TCE)	ND	0.322	1	µG/L	U	duplicate
69MW1602A	04/09/99	112.5	WA	SW8260	1,1,1-TRICHLOROETHANE	ND	0.328	1	µG/L	U	
69MW1602A	04/09/99	112.5	WA	SW8260	1,1-DICHLOROETHENE	ND	0.532	1	µG/L	U	
69MW1602A	04/09/99	112.5	WA	SW8260	BENZENE	ND	0.371	1	µG/L	U	
69MW1602A	04/09/99	112.5	WA	SW8260	CARBON TETRACHLORIDE	ND	0.222	1	µG/L	U	
69MW1602A	04/09/99	112.5	WA	SW8260	CIS-1,2-DICHLOROETHENE	ND	0.215	1	µG/L	U	
69MW1602A	04/09/99	112.5	WA	SW8260	ETHYLBENZENE	ND	0.282	1	µG/L	U	
69MW1602A	04/09/99	112.5	WA	SW8260	M,P-XYLENE (SUM OF ISOMERS)	ND	0.406	1	µG/L	U	
69MW1602A	04/09/99	112.5	WA	SW8260	O-XYLENE (1,2-DIMETHYLBENZENE)	ND	0.289	1	µG/L	U	
69MW1602A	04/09/99	112.5	WA	SW8260	TETRACHLOROETHENE(PCE)	ND	0.288	1	µG/L	U	

Volatile Organic Compound Analysis of Borehole Water Samples From New FS-29 Wells

Location	Date	Depth	Matrix	Test	Analyte	Result	DL	RL	Units	Qual
69MW1602A	04/09/99	112.5	WA	SW8260	TOLUENE	ND	0.197	1	µG/L	U
69MW1602A	04/09/99	112.5	WA	SW8260	TRANS-1,2-DICHLOROETHENE	ND	0.168	1	µG/L	U
69MW1602A	04/09/99	112.5	WA	SW8260	TRICHLOROETHENE(TCE)	ND	0.322	1	µG/L	U
69MW1602A	04/09/99	122.5	WA	SW8260	1,1,1-TRICHLOROETHANE	ND	0.328	1	µG/L	U
69MW1602A	04/09/99	122.5	WA	SW8260	1,1-DICHLOROETHENE	ND	0.532	1	µG/L	U
69MW1602A	04/09/99	122.5	WA	SW8260	BENZENE	ND	0.371	1	µG/L	U
69MW1602A	04/09/99	122.5	WA	SW8260	CARBON TETRACHLORIDE	ND	0.222	1	µG/L	U
69MW1602A	04/09/99	122.5	WA	SW8260	CIS-1,2-DICHLOROETHENE	ND	0.215	1	µG/L	U
69MW1602A	04/09/99	122.5	WA	SW8260	ETHYLBENZENE	ND	0.282	1	µG/L	U
69MW1602A	04/09/99	122.5	WA	SW8260	M,P-XYLENE (SUM OF ISOMERS)	ND	0.406	1	µG/L	U
69MW1602A	04/09/99	122.5	WA	SW8260	O-XYLENE (1,2-DIMETHYLBENZENE)	ND	0.289	1	µG/L	U
69MW1602A	04/09/99	122.5	WA	SW8260	TETRACHLOROETHENE(PCE)	ND	0.288	1	µG/L	U
69MW1602A	04/09/99	122.5	WA	SW8260	TOLUENE	ND	0.197	1	µG/L	U
69MW1602A	04/09/99	122.5	WA	SW8260	TRANS-1,2-DICHLOROETHENE	ND	0.168	1	µG/L	U
69MW1602A	04/09/99	122.5	WA	SW8260	TRICHLOROETHENE(TCE)	ND	0.322	1	µG/L	U
69MW1602A	04/09/99	132.5	WA	SW8260	1,1,1-TRICHLOROETHANE	ND	0.328	1	µG/L	U
69MW1602A	04/09/99	132.5	WA	SW8260	1,1-DICHLOROETHENE	ND	0.532	1	µG/L	U
69MW1602A	04/09/99	132.5	WA	SW8260	BENZENE	ND	0.371	1	µG/L	U
69MW1602A	04/09/99	132.5	WA	SW8260	CARBON TETRACHLORIDE	ND	0.222	1	µG/L	U
69MW1602A	04/09/99	132.5	WA	SW8260	CIS-1,2-DICHLOROETHENE	ND	0.215	1	µG/L	U
69MW1602A	04/09/99	132.5	WA	SW8260	ETHYLBENZENE	ND	0.282	1	µG/L	U
69MW1602A	04/09/99	132.5	WA	SW8260	M,P-XYLENE (SUM OF ISOMERS)	ND	0.406	1	µG/L	U
69MW1602A	04/09/99	132.5	WA	SW8260	O-XYLENE (1,2-DIMETHYLBENZENE)	ND	0.289	1	µG/L	U
69MW1602A	04/09/99	132.5	WA	SW8260	TETRACHLOROETHENE(PCE)	ND	0.288	1	µG/L	U
69MW1602A	04/09/99	132.5	WA	SW8260	TOLUENE	ND	0.197	1	µG/L	U
69MW1602A	04/09/99	132.5	WA	SW8260	TRANS-1,2-DICHLOROETHENE	ND	0.168	1	µG/L	U
69MW1602A	04/09/99	132.5	WA	SW8260	TRICHLOROETHENE(TCE)	ND	0.322	1	µG/L	U
69MW1602A	04/09/99	142.5	WA	SW8260	1,1,1-TRICHLOROETHANE	ND	0.328	1	µG/L	U
69MW1602A	04/09/99	142.5	WA	SW8260	1,1-DICHLOROETHENE	ND	0.532	1	µG/L	U
69MW1602A	04/09/99	142.5	WA	SW8260	BENZENE	ND	0.371	1	µG/L	U
69MW1602A	04/09/99	142.5	WA	SW8260	CARBON TETRACHLORIDE	ND	0.222	1	µG/L	U
69MW1602A	04/09/99	142.5	WA	SW8260	CIS-1,2-DICHLOROETHENE	ND	0.215	1	µG/L	U
69MW1602A	04/09/99	142.5	WA	SW8260	ETHYLBENZENE	ND	0.282	1	µG/L	U
69MW1602A	04/09/99	142.5	WA	SW8260	M,P-XYLENE (SUM OF ISOMERS)	ND	0.406	1	µG/L	U
69MW1602A	04/09/99	142.5	WA	SW8260	O-XYLENE (1,2-DIMETHYLBENZENE)	ND	0.289	1	µG/L	U
69MW1602A	04/09/99	142.5	WA	SW8260	TETRACHLOROETHENE(PCE)	ND	0.288	1	µG/L	U
69MW1602A	04/09/99	142.5	WA	SW8260	TOLUENE	ND	0.197	1	µG/L	U
69MW1602A	04/09/99	142.5	WA	SW8260	TRANS-1,2-DICHLOROETHENE	ND	0.168	1	µG/L	U
69MW1602A	04/09/99	142.5	WA	SW8260	TRICHLOROETHENE(TCE)	ND	0.322	1	µG/L	U

Volatile Organic Compound Analysis of Borehole Water Samples From New FS-29 Wells

Location	Date	Depth	Matrix	Test	Analyte	Result	DL	RL	Units	Qual	
69MW1602A	04/09/99	152.5	WA	SW8260	1,1,1-TRICHLOROETHANE	ND	0.328	1	µG/L	U	
69MW1602A	04/09/99	152.5	WA	SW8260	1,1-DICHLOROETHENE	ND	0.532	1	µG/L	U	
69MW1602A	04/09/99	152.5	WA	SW8260	BENZENE	ND	0.371	1	µG/L	U	
69MW1602A	04/09/99	152.5	WA	SW8260	CARBON TETRACHLORIDE	ND	0.222	1	µG/L	U	
69MW1602A	04/09/99	152.5	WA	SW8260	CIS-1,2-DICHLOROETHENE	ND	0.215	1	µG/L	U	
69MW1602A	04/09/99	152.5	WA	SW8260	ETHYLBENZENE	ND	0.282	1	µG/L	U	
69MW1602A	04/09/99	152.5	WA	SW8260	M,P-XYLENE (SUM OF ISOMERS)	ND	0.406	1	µG/L	U	
69MW1602A	04/09/99	152.5	WA	SW8260	O-XYLENE (1,2-DIMETHYLBENZENE)	ND	0.289	1	µG/L	U	
69MW1602A	04/09/99	152.5	WA	SW8260	TETRACHLOROETHENE(PCE)	ND	0.288	1	µG/L	U	
69MW1602A	04/09/99	152.5	WA	SW8260	TOLUENE	ND	0.197	1	µG/L	U	
69MW1602A	04/09/99	152.5	WA	SW8260	TRANS-1,2-DICHLOROETHENE	ND	0.168	1	µG/L	U	
69MW1602A	04/09/99	152.5	WA	SW8260	TRICHLOROETHENE(TCE)	ND	0.322	1	µG/L	U	
69MW1602A	04/09/99	162.5	WA	SW8260	1,1,1-TRICHLOROETHANE	ND	0.328	1	µG/L	U	
69MW1602A	04/09/99	162.5	WA	SW8260	1,1-DICHLOROETHENE	ND	0.532	1	µG/L	U	
69MW1602A	04/09/99	162.5	WA	SW8260	BENZENE	ND	0.371	1	µG/L	U	
69MW1602A	04/09/99	162.5	WA	SW8260	CARBON TETRACHLORIDE	ND	0.222	1	µG/L	U	
69MW1602A	04/09/99	162.5	WA	SW8260	CIS-1,2-DICHLOROETHENE	ND	0.215	1	µG/L	U	
69MW1602A	04/09/99	162.5	WA	SW8260	ETHYLBENZENE	ND	0.282	1	µG/L	U	
69MW1602A	04/09/99	162.5	WA	SW8260	M,P-XYLENE (SUM OF ISOMERS)	ND	0.406	1	µG/L	U	
69MW1602A	04/09/99	162.5	WA	SW8260	O-XYLENE (1,2-DIMETHYLBENZENE)	ND	0.289	1	µG/L	U	
69MW1602A	04/09/99	162.5	WA	SW8260	TETRACHLOROETHENE(PCE)	ND	0.288	1	µG/L	U	
69MW1602A	04/09/99	162.5	WA	SW8260	TOLUENE	ND	0.197	1	µG/L	U	
69MW1602A	04/09/99	162.5	WA	SW8260	TRANS-1,2-DICHLOROETHENE	ND	0.168	1	µG/L	U	
69MW1602A	04/09/99	162.5	WA	SW8260	TRICHLOROETHENE(TCE)	ND	0.322	1	µG/L	U	
69MW1602A	04/09/99	172.5	WA	SW8260	1,1,1-TRICHLOROETHANE	ND	0.328	1	µG/L	U	
69MW1602A	04/09/99	172.5	WA	SW8260	1,1-DICHLOROETHENE	ND	0.532	1	µG/L	U	
69MW1602A	04/09/99	172.5	WA	SW8260	BENZENE	ND	0.371	1	µG/L	U	
69MW1602A	04/09/99	172.5	WA	SW8260	CARBON TETRACHLORIDE	ND	0.222	1	µG/L	U	
69MW1602A	04/09/99	172.5	WA	SW8260	CIS-1,2-DICHLOROETHENE	ND	0.215	1	µG/L	U	
69MW1602A	04/09/99	172.5	WA	SW8260	ETHYLBENZENE	ND	0.282	1	µG/L	U	
69MW1602A	04/09/99	172.5	WA	SW8260	M,P-XYLENE (SUM OF ISOMERS)	ND	0.406	1	µG/L	U	
69MW1602A	04/09/99	172.5	WA	SW8260	O-XYLENE (1,2-DIMETHYLBENZENE)	ND	0.289	1	µG/L	U	
69MW1602A	04/09/99	172.5	WA	SW8260	TETRACHLOROETHENE(PCE)	ND	0.288	1	µG/L	U	
69MW1602A	04/09/99	172.5	WA	SW8260	TOLUENE	ND	0.197	1	µG/L	U	
69MW1602A	04/09/99	172.5	WA	SW8260	TRANS-1,2-DICHLOROETHENE	ND	0.168	1	µG/L	U	
69MW1602A	04/09/99	172.5	WA	SW8260	TRICHLOROETHENE(TCE)	ND	0.322	1	µG/L	U	
69MW1602A	04/12/99	182.5	WA	SW8260	1,1,1-TRICHLOROETHANE	ND	0.328	1	µG/L	U	
69MW1602A	04/12/99	182.5	WA	SW8260	1,1-DICHLOROETHENE	ND	0.532	1	µG/L	U	
69MW1602A	04/12/99	182.5	WA	SW8260	BENZENE	ND	0.371	1	µG/L	U	

Volatile Organic Compound Analysis of Borehole Water Samples From New FS-29 Wells

Location	Date	Depth	Matrix	Test	Analyte	Result	DL	RL	Units	Qual	
69MW1602A	04/12/99	182.5	WA	SW8260	CARBON TETRACHLORIDE	ND	0.222	1	µG/L	U	
69MW1602A	04/12/99	182.5	WA	SW8260	CIS-1,2-DICHLOROETHENE	ND	0.215	1	µG/L	U	
69MW1602A	04/12/99	182.5	WA	SW8260	ETHYLBENZENE	ND	0.282	1	µG/L	U	
69MW1602A	04/12/99	182.5	WA	SW8260	M,P-XYLENE (SUM OF ISOMERS)	ND	0.406	1	µG/L	U	
69MW1602A	04/12/99	182.5	WA	SW8260	O-XYLENE (1,2-DIMETHYLBENZENE)	ND	0.289	1	µG/L	U	
69MW1602A	04/12/99	182.5	WA	SW8260	TETRACHLOROETHENE(PCE)	ND	0.288	1	µG/L	U	
69MW1602A	04/12/99	182.5	WA	SW8260	TOLUENE	ND	0.197	1	µG/L	U	
69MW1602A	04/12/99	182.5	WA	SW8260	TRANS-1,2-DICHLOROETHENE	ND	0.168	1	µG/L	U	
69MW1602A	04/12/99	182.5	WA	SW8260	TRICHLOROETHENE(TCE)	ND	0.322	1	µG/L	U	
69MW1602A	04/12/99	192.5	WA	SW8260	1,1,1-TRICHLOROETHANE	ND	0.328	1	µG/L	U	
69MW1602A	04/12/99	192.5	WA	SW8260	1,1-DICHLOROETHENE	ND	0.532	1	µG/L	U	
69MW1602A	04/12/99	192.5	WA	SW8260	BENZENE	ND	0.371	1	µG/L	U	
69MW1602A	04/12/99	192.5	WA	SW8260	CARBON TETRACHLORIDE	ND	0.222	1	µG/L	U	
69MW1602A	04/12/99	192.5	WA	SW8260	CIS-1,2-DICHLOROETHENE	ND	0.215	1	µG/L	U	
69MW1602A	04/12/99	192.5	WA	SW8260	ETHYLBENZENE	ND	0.282	1	µG/L	U	
69MW1602A	04/12/99	192.5	WA	SW8260	M,P-XYLENE (SUM OF ISOMERS)	ND	0.406	1	µG/L	U	
69MW1602A	04/12/99	192.5	WA	SW8260	O-XYLENE (1,2-DIMETHYLBENZENE)	ND	0.289	1	µG/L	U	
69MW1602A	04/12/99	192.5	WA	SW8260	TETRACHLOROETHENE(PCE)	ND	0.288	1	µG/L	U	
69MW1602A	04/12/99	192.5	WA	SW8260	TOLUENE	ND	0.197	1	µG/L	U	
69MW1602A	04/12/99	192.5	WA	SW8260	TRANS-1,2-DICHLOROETHENE	ND	0.168	1	µG/L	U	
69MW1602A	04/12/99	192.5	WA	SW8260	TRICHLOROETHENE(TCE)	ND	0.322	1	µG/L	U	
69MW1602A	04/12/99	202.5	WA	SW8260	1,1,1-TRICHLOROETHANE	ND	0.328	1	µG/L	U	
69MW1602A	04/12/99	202.5	WA	SW8260	1,1,1-TRICHLOROETHANE	ND	0.328	1	µG/L	U	duplicate
69MW1602A	04/12/99	202.5	WA	SW8260	1,1-DICHLOROETHENE	ND	0.532	1	µG/L	U	
69MW1602A	04/12/99	202.5	WA	SW8260	1,1-DICHLOROETHENE	ND	0.532	1	µG/L	U	duplicate
69MW1602A	04/12/99	202.5	WA	SW8260	BENZENE	ND	0.371	1	µG/L	U	
69MW1602A	04/12/99	202.5	WA	SW8260	BENZENE	ND	0.371	1	µG/L	U	duplicate
69MW1602A	04/12/99	202.5	WA	SW8260	CARBON TETRACHLORIDE	ND	0.222	1	µG/L	U	
69MW1602A	04/12/99	202.5	WA	SW8260	CARBON TETRACHLORIDE	ND	0.222	1	µG/L	U	duplicate
69MW1602A	04/12/99	202.5	WA	SW8260	CIS-1,2-DICHLOROETHENE	ND	0.215	1	µG/L	U	
69MW1602A	04/12/99	202.5	WA	SW8260	CIS-1,2-DICHLOROETHENE	ND	0.215	1	µG/L	U	duplicate
69MW1602A	04/12/99	202.5	WA	SW8260	ETHYLBENZENE	ND	0.282	1	µG/L	U	
69MW1602A	04/12/99	202.5	WA	SW8260	ETHYLBENZENE	ND	0.282	1	µG/L	U	duplicate
69MW1602A	04/12/99	202.5	WA	SW8260	M,P-XYLENE (SUM OF ISOMERS)	ND	0.406	1	µG/L	U	
69MW1602A	04/12/99	202.5	WA	SW8260	M,P-XYLENE (SUM OF ISOMERS)	ND	0.406	1	µG/L	U	duplicate
69MW1602A	04/12/99	202.5	WA	SW8260	O-XYLENE (1,2-DIMETHYLBENZENE)	ND	0.289	1	µG/L	U	
69MW1602A	04/12/99	202.5	WA	SW8260	O-XYLENE (1,2-DIMETHYLBENZENE)	ND	0.289	1	µG/L	U	duplicate
69MW1602A	04/12/99	202.5	WA	SW8260	TETRACHLOROETHENE(PCE)	ND	0.288	1	µG/L	U	
69MW1602A	04/12/99	202.5	WA	SW8260	TETRACHLOROETHENE(PCE)	ND	0.288	1	µG/L	U	duplicate

Volatile Organic Compound Analysis of Borehole Water Samples From New FS-29 Wells

Location	Date	Depth	Matrix	Test	Analyte	Result	DL	RL	Units	Qual	
69MW1602A	04/12/99	202.5	WA	SW8260	TOLUENE	ND	0.197	1	µG/L	U	
69MW1602A	04/12/99	202.5	WA	SW8260	TOLUENE	ND	0.197	1	µG/L	U	duplicate
69MW1602A	04/12/99	202.5	WA	SW8260	TRANS-1,2-DICHLOROETHENE	ND	0.168	1	µG/L	U	
69MW1602A	04/12/99	202.5	WA	SW8260	TRANS-1,2-DICHLOROETHENE	ND	0.168	1	µG/L	U	duplicate
69MW1602A	04/12/99	202.5	WA	SW8260	TRICHLOROETHENE(TCE)	ND	0.322	1	µG/L	U	
69MW1602A	04/12/99	202.5	WA	SW8260	TRICHLOROETHENE(TCE)	ND	0.322	1	µG/L	U	duplicate
69MW1602A	04/12/99	212.5	WA	SW8260	1,1,1-TRICHLOROETHANE	ND	0.328	1	µG/L	U	
69MW1602A	04/12/99	212.5	WA	SW8260	1,1-DICHLOROETHENE	ND	0.532	1	µG/L	U	
69MW1602A	04/12/99	212.5	WA	SW8260	BENZENE	ND	0.371	1	µG/L	U	
69MW1602A	04/12/99	212.5	WA	SW8260	CARBON TETRACHLORIDE	ND	0.222	1	µG/L	U	
69MW1602A	04/12/99	212.5	WA	SW8260	CIS-1,2-DICHLOROETHENE	ND	0.215	1	µG/L	U	
69MW1602A	04/12/99	212.5	WA	SW8260	ETHYLBENZENE	ND	0.282	1	µG/L	U	
69MW1602A	04/12/99	212.5	WA	SW8260	M,P-XYLENE (SUM OF ISOMERS)	ND	0.406	1	µG/L	U	
69MW1602A	04/12/99	212.5	WA	SW8260	O-XYLENE (1,2-DIMETHYLBENZENE)	ND	0.289	1	µG/L	U	
69MW1602A	04/12/99	212.5	WA	SW8260	TETRACHLOROETHENE(PCE)	ND	0.288	1	µG/L	U	
69MW1602A	04/12/99	212.5	WA	SW8260	TOLUENE	ND	0.197	1	µG/L	U	
69MW1602A	04/12/99	212.5	WA	SW8260	TRANS-1,2-DICHLOROETHENE	ND	0.168	1	µG/L	U	
69MW1602A	04/12/99	212.5	WA	SW8260	TRICHLOROETHENE(TCE)	ND	0.322	1	µG/L	U	
69MW1602A	04/12/99	222.5	WA	SW8260	1,1,1-TRICHLOROETHANE	ND	0.328	1	µG/L	U	
69MW1602A	04/12/99	222.5	WA	SW8260	1,1-DICHLOROETHENE	ND	0.532	1	µG/L	U	
69MW1602A	04/12/99	222.5	WA	SW8260	BENZENE	ND	0.371	1	µG/L	U	
69MW1602A	04/12/99	222.5	WA	SW8260	CARBON TETRACHLORIDE	ND	0.222	1	µG/L	U	
69MW1602A	04/12/99	222.5	WA	SW8260	CIS-1,2-DICHLOROETHENE	ND	0.215	1	µG/L	U	
69MW1602A	04/12/99	222.5	WA	SW8260	ETHYLBENZENE	ND	0.282	1	µG/L	U	
69MW1602A	04/12/99	222.5	WA	SW8260	M,P-XYLENE (SUM OF ISOMERS)	ND	0.406	1	µG/L	U	
69MW1602A	04/12/99	222.5	WA	SW8260	O-XYLENE (1,2-DIMETHYLBENZENE)	ND	0.289	1	µG/L	U	
69MW1602A	04/12/99	222.5	WA	SW8260	TETRACHLOROETHENE(PCE)	ND	0.288	1	µG/L	U	
69MW1602A	04/12/99	222.5	WA	SW8260	TOLUENE	ND	0.197	1	µG/L	U	
69MW1602A	04/12/99	222.5	WA	SW8260	TRANS-1,2-DICHLOROETHENE	ND	0.168	1	µG/L	U	
69MW1602A	04/12/99	222.5	WA	SW8260	TRICHLOROETHENE(TCE)	ND	0.322	1	µG/L	U	
69MW1602A	04/12/99	232.5	WA	SW8260	1,1,1-TRICHLOROETHANE	ND	0.328	1	µG/L	U	
69MW1602A	04/12/99	232.5	WA	SW8260	1,1-DICHLOROETHENE	ND	0.532	1	µG/L	U	
69MW1602A	04/12/99	232.5	WA	SW8260	BENZENE	ND	0.371	1	µG/L	U	
69MW1602A	04/12/99	232.5	WA	SW8260	CARBON TETRACHLORIDE	ND	0.222	1	µG/L	U	
69MW1602A	04/12/99	232.5	WA	SW8260	CIS-1,2-DICHLOROETHENE	ND	0.215	1	µG/L	U	
69MW1602A	04/12/99	232.5	WA	SW8260	ETHYLBENZENE	ND	0.282	1	µG/L	U	
69MW1602A	04/12/99	232.5	WA	SW8260	M,P-XYLENE (SUM OF ISOMERS)	ND	0.406	1	µG/L	U	
69MW1602A	04/12/99	232.5	WA	SW8260	O-XYLENE (1,2-DIMETHYLBENZENE)	ND	0.289	1	µG/L	U	
69MW1602A	04/12/99	232.5	WA	SW8260	TETRACHLOROETHENE(PCE)	ND	0.288	1	µG/L	U	

Volatile Organic Compound Analysis of Borehole Water Samples From New FS-29 Wells

Location	Date	Depth	Matrix	Test	Analyte	Result	DL	RL	Units	Qual	
69MW1602A	04/12/99	232.5	WA	SW8260	TOLUENE	ND	0.197	1	µG/L	U	
69MW1602A	04/12/99	232.5	WA	SW8260	TRANS-1,2-DICHLOROETHENE	ND	0.168	1	µG/L	U	
69MW1602A	04/12/99	232.5	WA	SW8260	TRICHLOROETHENE(TCE)	ND	0.322	1	µG/L	U	
69MW1602A	04/12/99	242.5	WA	SW8260	1,1,1-TRICHLOROETHANE	ND	0.328	1	µG/L	U	
69MW1602A	04/12/99	242.5	WA	SW8260	1,1-DICHLOROETHENE	ND	0.532	1	µG/L	U	
69MW1602A	04/12/99	242.5	WA	SW8260	BENZENE	ND	0.371	1	µG/L	U	
69MW1602A	04/12/99	242.5	WA	SW8260	CARBON TETRACHLORIDE	ND	0.222	1	µG/L	U	
69MW1602A	04/12/99	242.5	WA	SW8260	CIS-1,2-DICHLOROETHENE	ND	0.215	1	µG/L	U	
69MW1602A	04/12/99	242.5	WA	SW8260	ETHYLBENZENE	ND	0.282	1	µG/L	U	
69MW1602A	04/12/99	242.5	WA	SW8260	M,P-XYLENE (SUM OF ISOMERS)	ND	0.406	1	µG/L	U	
69MW1602A	04/12/99	242.5	WA	SW8260	O-XYLENE (1,2-DIMETHYLBENZENE)	ND	0.289	1	µG/L	U	
69MW1602A	04/12/99	242.5	WA	SW8260	TETRACHLOROETHENE(PCE)	ND	0.288	1	µG/L	U	
69MW1602A	04/12/99	242.5	WA	SW8260	TOLUENE	ND	0.197	1	µG/L	U	
69MW1602A	04/12/99	242.5	WA	SW8260	TRANS-1,2-DICHLOROETHENE	ND	0.168	1	µG/L	U	
69MW1602A	04/12/99	242.5	WA	SW8260	TRICHLOROETHENE(TCE)	ND	0.322	1	µG/L	U	
69MW1602A	04/12/99	262.5	WA	SW8260	1,1,1-TRICHLOROETHANE	ND	0.328	1	µG/L	U	
69MW1602A	04/12/99	262.5	WA	SW8260	1,1-DICHLOROETHENE	ND	0.532	1	µG/L	U	
69MW1602A	04/12/99	262.5	WA	SW8260	BENZENE	ND	0.371	1	µG/L	U	
69MW1602A	04/12/99	262.5	WA	SW8260	CARBON TETRACHLORIDE	ND	0.222	1	µG/L	U	
69MW1602A	04/12/99	262.5	WA	SW8260	CIS-1,2-DICHLOROETHENE	ND	0.215	1	µG/L	U	
69MW1602A	04/12/99	262.5	WA	SW8260	ETHYLBENZENE	ND	0.282	1	µG/L	U	
69MW1602A	04/12/99	262.5	WA	SW8260	M,P-XYLENE (SUM OF ISOMERS)	ND	0.406	1	µG/L	U	
69MW1602A	04/12/99	262.5	WA	SW8260	O-XYLENE (1,2-DIMETHYLBENZENE)	ND	0.289	1	µG/L	U	
69MW1602A	04/12/99	262.5	WA	SW8260	TETRACHLOROETHENE(PCE)	ND	0.288	1	µG/L	U	
69MW1602A	04/12/99	262.5	WA	SW8260	TOLUENE	ND	0.197	1	µG/L	U	
69MW1602A	04/12/99	262.5	WA	SW8260	TRANS-1,2-DICHLOROETHENE	ND	0.168	1	µG/L	U	
69MW1602A	04/12/99	262.5	WA	SW8260	TRICHLOROETHENE(TCE)	ND	0.322	1	µG/L	U	
69MW1603A	04/20/99	92.5	WA	SW8260	1,1,1-TRICHLOROETHANE	ND	0.328	1	µG/L	U	
69MW1603A	04/20/99	92.5	WA	SW8260	1,1-DICHLOROETHENE	ND	0.532	1	µG/L	U	
69MW1603A	04/20/99	92.5	WA	SW8260	BENZENE	ND	0.371	1	µG/L	U	
69MW1603A	04/20/99	92.5	WA	SW8260	CARBON TETRACHLORIDE	ND	0.222	1	µG/L	U	
69MW1603A	04/20/99	92.5	WA	SW8260	CIS-1,2-DICHLOROETHENE	ND	0.215	1	µG/L	U	
69MW1603A	04/20/99	92.5	WA	SW8260	ETHYLBENZENE	ND	0.282	1	µG/L	U	
69MW1603A	04/20/99	92.5	WA	SW8260	M,P-XYLENE (SUM OF ISOMERS)	ND	0.406	1	µG/L	U	
69MW1603A	04/20/99	92.5	WA	SW8260	O-XYLENE (1,2-DIMETHYLBENZENE)	ND	0.289	1	µG/L	U	
69MW1603A	04/20/99	92.5	WA	SW8260	TETRACHLOROETHENE(PCE)	ND	0.288	1	µG/L	U	
69MW1603A	04/20/99	92.5	WA	SW8260	TOLUENE	ND	0.197	1	µG/L	U	
69MW1603A	04/20/99	92.5	WA	SW8260	TRANS-1,2-DICHLOROETHENE	ND	0.168	1	µG/L	U	
69MW1603A	04/20/99	92.5	WA	SW8260	TRICHLOROETHENE(TCE)	ND	0.322	1	µG/L	U	



Volatile Organic Compound Analysis of Borehole Water Samples From New FS-29 Wells

Location	Date	Depth	Matrix	Test	Analyte	Result	DL	RL	Units	Qual	
69MW1603A	04/20/99	102.5	WA	SW8260	1,1,1-TRICHLOROETHANE	ND	0.328	1	µG/L	U	
69MW1603A	04/20/99	102.5	WA	SW8260	1,1-DICHLOROETHENE	ND	0.532	1	µG/L	U	
69MW1603A	04/20/99	102.5	WA	SW8260	BENZENE	ND	0.371	1	µG/L	U	
69MW1603A	04/20/99	102.5	WA	SW8260	CARBON TETRACHLORIDE	ND	0.222	1	µG/L	U	
69MW1603A	04/20/99	102.5	WA	SW8260	CIS-1,2-DICHLOROETHENE	ND	0.215	1	µG/L	U	
69MW1603A	04/20/99	102.5	WA	SW8260	ETHYLBENZENE	ND	0.282	1	µG/L	U	
69MW1603A	04/20/99	102.5	WA	SW8260	M,P-XYLENE (SUM OF ISOMERS)	ND	0.406	1	µG/L	U	
69MW1603A	04/20/99	102.5	WA	SW8260	O-XYLENE (1,2-DIMETHYLBENZENE)	ND	0.289	1	µG/L	U	
69MW1603A	04/20/99	102.5	WA	SW8260	TETRACHLOROETHENE(PCE)	ND	0.288	1	µG/L	U	
69MW1603A	04/20/99	102.5	WA	SW8260	TOLUENE	ND	0.197	1	µG/L	U	
69MW1603A	04/20/99	102.5	WA	SW8260	TRANS-1,2-DICHLOROETHENE	ND	0.168	1	µG/L	U	
69MW1603A	04/20/99	102.5	WA	SW8260	TRICHLOROETHENE(TCE)	ND	0.322	1	µG/L	U	
69MW1603A	04/20/99	112.5	WA	SW8260	1,1,1-TRICHLOROETHANE	ND	0.328	1	µG/L	U	
69MW1603A	04/20/99	112.5	WA	SW8260	1,1,1-TRICHLOROETHANE	ND	0.328	1	µG/L	U	duplicate
69MW1603A	04/20/99	112.5	WA	SW8260	1,1-DICHLOROETHENE	ND	0.532	1	µG/L	U	
69MW1603A	04/20/99	112.5	WA	SW8260	1,1-DICHLOROETHENE	ND	0.532	1	µG/L	U	duplicate
69MW1603A	04/20/99	112.5	WA	SW8260	BENZENE	ND	0.371	1	µG/L	U	
69MW1603A	04/20/99	112.5	WA	SW8260	BENZENE	ND	0.371	1	µG/L	U	duplicate
69MW1603A	04/20/99	112.5	WA	SW8260	CARBON TETRACHLORIDE	ND	0.222	1	µG/L	U	
69MW1603A	04/20/99	112.5	WA	SW8260	CARBON TETRACHLORIDE	ND	0.222	1	µG/L	U	duplicate
69MW1603A	04/20/99	112.5	WA	SW8260	CIS-1,2-DICHLOROETHENE	ND	0.215	1	µG/L	U	
69MW1603A	04/20/99	112.5	WA	SW8260	CIS-1,2-DICHLOROETHENE	ND	0.215	1	µG/L	U	duplicate
69MW1603A	04/20/99	112.5	WA	SW8260	ETHYLBENZENE	ND	0.282	1	µG/L	U	
69MW1603A	04/20/99	112.5	WA	SW8260	ETHYLBENZENE	ND	0.282	1	µG/L	U	duplicate
69MW1603A	04/20/99	112.5	WA	SW8260	M,P-XYLENE (SUM OF ISOMERS)	ND	0.406	1	µG/L	U	
69MW1603A	04/20/99	112.5	WA	SW8260	M,P-XYLENE (SUM OF ISOMERS)	ND	0.406	1	µG/L	U	duplicate
69MW1603A	04/20/99	112.5	WA	SW8260	O-XYLENE (1,2-DIMETHYLBENZENE)	ND	0.289	1	µG/L	U	
69MW1603A	04/20/99	112.5	WA	SW8260	O-XYLENE (1,2-DIMETHYLBENZENE)	ND	0.289	1	µG/L	U	duplicate
69MW1603A	04/20/99	112.5	WA	SW8260	TETRACHLOROETHENE(PCE)	ND	0.288	1	µG/L	U	
69MW1603A	04/20/99	112.5	WA	SW8260	TETRACHLOROETHENE(PCE)	ND	0.288	1	µG/L	U	duplicate
69MW1603A	04/20/99	112.5	WA	SW8260	TOLUENE	ND	0.197	1	µG/L	U	
69MW1603A	04/20/99	112.5	WA	SW8260	TOLUENE	ND	0.197	1	µG/L	U	duplicate
69MW1603A	04/20/99	112.5	WA	SW8260	TRANS-1,2-DICHLOROETHENE	ND	0.168	1	µG/L	U	
69MW1603A	04/20/99	112.5	WA	SW8260	TRANS-1,2-DICHLOROETHENE	ND	0.168	1	µG/L	U	duplicate
69MW1603A	04/20/99	112.5	WA	SW8260	TRICHLOROETHENE(TCE)	ND	0.322	1	µG/L	U	
69MW1603A	04/20/99	112.5	WA	SW8260	TRICHLOROETHENE(TCE)	ND	0.322	1	µG/L	U	duplicate
69MW1603A	04/20/99	122.5	WA	SW8260	1,1,1-TRICHLOROETHANE	ND	0.328	1	µG/L	U	
69MW1603A	04/20/99	122.5	WA	SW8260	1,1-DICHLOROETHENE	ND	0.532	1	µG/L	U	
69MW1603A	04/20/99	122.5	WA	SW8260	BENZENE	ND	0.371	1	µG/L	U	

Volatile Organic Compound Analysis of Borehole Water Samples From New FS-29 Wells

Location	Date	Depth	Matrix	Test	Analyte	Result	DL	RL	Units	Qual
69MW1603A	04/20/99	122.5	WA	SW8260	CARBON TETRACHLORIDE	ND	0.222	1	µG/L	U
69MW1603A	04/20/99	122.5	WA	SW8260	CIS-1,2-DICHLOROETHENE	ND	0.215	1	µG/L	U
69MW1603A	04/20/99	122.5	WA	SW8260	ETHYLBENZENE	ND	0.282	1	µG/L	U
69MW1603A	04/20/99	122.5	WA	SW8260	M,P-XYLENE (SUM OF ISOMERS)	ND	0.406	1	µG/L	U
69MW1603A	04/20/99	122.5	WA	SW8260	O-XYLENE (1,2-DIMETHYLBENZENE)	ND	0.289	1	µG/L	U
69MW1603A	04/20/99	122.5	WA	SW8260	TETRACHLOROETHENE(PCE)	ND	0.288	1	µG/L	U
69MW1603A	04/20/99	122.5	WA	SW8260	TOLUENE	ND	0.197	1	µG/L	U
69MW1603A	04/20/99	122.5	WA	SW8260	TRANS-1,2-DICHLOROETHENE	ND	0.168	1	µG/L	U
69MW1603A	04/20/99	122.5	WA	SW8260	TRICHLOROETHENE(TCE)	ND	0.322	1	µG/L	U
69MW1603A	04/20/99	132.5	WA	SW8260	1,1,1-TRICHLOROETHANE	ND	0.328	1	µG/L	U
69MW1603A	04/20/99	132.5	WA	SW8260	1,1-DICHLOROETHENE	ND	0.532	1	µG/L	U
69MW1603A	04/20/99	132.5	WA	SW8260	BENZENE	ND	0.371	1	µG/L	U
69MW1603A	04/20/99	132.5	WA	SW8260	CARBON TETRACHLORIDE	ND	0.222	1	µG/L	U
69MW1603A	04/20/99	132.5	WA	SW8260	CIS-1,2-DICHLOROETHENE	ND	0.215	1	µG/L	U
69MW1603A	04/20/99	132.5	WA	SW8260	ETHYLBENZENE	ND	0.282	1	µG/L	U
69MW1603A	04/20/99	132.5	WA	SW8260	M,P-XYLENE (SUM OF ISOMERS)	ND	0.406	1	µG/L	U
69MW1603A	04/20/99	132.5	WA	SW8260	O-XYLENE (1,2-DIMETHYLBENZENE)	ND	0.289	1	µG/L	U
69MW1603A	04/20/99	132.5	WA	SW8260	TETRACHLOROETHENE(PCE)	ND	0.288	1	µG/L	U
69MW1603A	04/20/99	132.5	WA	SW8260	TOLUENE	ND	0.197	1	µG/L	U
69MW1603A	04/20/99	132.5	WA	SW8260	TRANS-1,2-DICHLOROETHENE	ND	0.168	1	µG/L	U
69MW1603A	04/20/99	132.5	WA	SW8260	TRICHLOROETHENE(TCE)	ND	0.322	1	µG/L	U
69MW1603A	04/20/99	142.5	WA	SW8260	1,1,1-TRICHLOROETHANE	ND	0.328	1	µG/L	U
69MW1603A	04/20/99	142.5	WA	SW8260	1,1-DICHLOROETHENE	ND	0.532	1	µG/L	U
69MW1603A	04/20/99	142.5	WA	SW8260	BENZENE	ND	0.371	1	µG/L	U
69MW1603A	04/20/99	142.5	WA	SW8260	CARBON TETRACHLORIDE	ND	0.222	1	µG/L	U
69MW1603A	04/20/99	142.5	WA	SW8260	CIS-1,2-DICHLOROETHENE	ND	0.215	1	µG/L	U
69MW1603A	04/20/99	142.5	WA	SW8260	ETHYLBENZENE	ND	0.282	1	µG/L	U
69MW1603A	04/20/99	142.5	WA	SW8260	M,P-XYLENE (SUM OF ISOMERS)	ND	0.406	1	µG/L	U
69MW1603A	04/20/99	142.5	WA	SW8260	O-XYLENE (1,2-DIMETHYLBENZENE)	ND	0.289	1	µG/L	U
69MW1603A	04/20/99	142.5	WA	SW8260	TETRACHLOROETHENE(PCE)	ND	0.288	1	µG/L	U
69MW1603A	04/20/99	142.5	WA	SW8260	TOLUENE	ND	0.197	1	µG/L	U
69MW1603A	04/20/99	142.5	WA	SW8260	TRANS-1,2-DICHLOROETHENE	ND	0.168	1	µG/L	U
69MW1603A	04/20/99	142.5	WA	SW8260	TRICHLOROETHENE(TCE)	ND	0.322	1	µG/L	U
69MW1603A	04/20/99	152.5	WA	SW8260	1,1,1-TRICHLOROETHANE	ND	0.328	1	µG/L	U
69MW1603A	04/20/99	152.5	WA	SW8260	1,1-DICHLOROETHENE	ND	0.532	1	µG/L	U
69MW1603A	04/20/99	152.5	WA	SW8260	BENZENE	ND	0.371	1	µG/L	U
69MW1603A	04/20/99	152.5	WA	SW8260	CARBON TETRACHLORIDE	ND	0.222	1	µG/L	U
69MW1603A	04/20/99	152.5	WA	SW8260	CIS-1,2-DICHLOROETHENE	ND	0.215	1	µG/L	U
69MW1603A	04/20/99	152.5	WA	SW8260	ETHYLBENZENE	ND	0.282	1	µG/L	U

Volatile Organic Compound Analysis of Borehole Water Samples From New FS-29 Wells

Location	Date	Depth	Matrix	Test	Analyte	Result	DL	RL	Units	Qual	
69MW1603A	04/20/99	152.5	WA	SW8260	M,P-XYLENE (SUM OF ISOMERS)	ND	0.406	1	µG/L	U	
69MW1603A	04/20/99	152.5	WA	SW8260	O-XYLENE (1,2-DIMETHYLBENZENE)	ND	0.289	1	µG/L	U	
69MW1603A	04/20/99	152.5	WA	SW8260	TETRACHLOROETHENE(PCE)	ND	0.288	1	µG/L	U	
69MW1603A	04/20/99	152.5	WA	SW8260	TOLUENE	ND	0.197	1	µG/L	U	
69MW1603A	04/20/99	152.5	WA	SW8260	TRANS-1,2-DICHLOROETHENE	ND	0.168	1	µG/L	U	
69MW1603A	04/20/99	152.5	WA	SW8260	TRICHLOROETHENE(TCE)	ND	0.322	1	µG/L	U	
69MW1603A	04/20/99	162.5	WA	SW8260	1,1,1-TRICHLOROETHANE	ND	0.328	1	µG/L	U	
69MW1603A	04/20/99	162.5	WA	SW8260	1,1-DICHLOROETHENE	ND	0.532	1	µG/L	U	
69MW1603A	04/20/99	162.5	WA	SW8260	BENZENE	ND	0.371	1	µG/L	U	
69MW1603A	04/20/99	162.5	WA	SW8260	CARBON TETRACHLORIDE	ND	0.222	1	µG/L	U	
69MW1603A	04/20/99	162.5	WA	SW8260	CIS-1,2-DICHLOROETHENE	ND	0.215	1	µG/L	U	
69MW1603A	04/20/99	162.5	WA	SW8260	ETHYLBENZENE	ND	0.282	1	µG/L	U	
69MW1603A	04/20/99	162.5	WA	SW8260	M,P-XYLENE (SUM OF ISOMERS)	ND	0.406	1	µG/L	U	
69MW1603A	04/20/99	162.5	WA	SW8260	O-XYLENE (1,2-DIMETHYLBENZENE)	ND	0.289	1	µG/L	U	
69MW1603A	04/20/99	162.5	WA	SW8260	TETRACHLOROETHENE(PCE)	ND	0.288	1	µG/L	U	
69MW1603A	04/20/99	162.5	WA	SW8260	TOLUENE	ND	0.197	1	µG/L	U	
69MW1603A	04/20/99	162.5	WA	SW8260	TRANS-1,2-DICHLOROETHENE	ND	0.168	1	µG/L	U	
69MW1603A	04/20/99	162.5	WA	SW8260	TRICHLOROETHENE(TCE)	ND	0.322	1	µG/L	U	
69MW1603A	04/21/99	172.5	WA	SW8260	1,1,1-TRICHLOROETHANE	ND	0.328	1	µG/L	U	
69MW1603A	04/21/99	172.5	WA	SW8260	1,1-DICHLOROETHENE	ND	0.532	1	µG/L	U	
69MW1603A	04/21/99	172.5	WA	SW8260	BENZENE	ND	0.371	1	µG/L	U	
69MW1603A	04/21/99	172.5	WA	SW8260	CARBON TETRACHLORIDE	ND	0.222	1	µG/L	U	
69MW1603A	04/21/99	172.5	WA	SW8260	CIS-1,2-DICHLOROETHENE	ND	0.215	1	µG/L	U	
69MW1603A	04/21/99	172.5	WA	SW8260	ETHYLBENZENE	ND	0.282	1	µG/L	U	
69MW1603A	04/21/99	172.5	WA	SW8260	M,P-XYLENE (SUM OF ISOMERS)	ND	0.406	1	µG/L	U	
69MW1603A	04/21/99	172.5	WA	SW8260	O-XYLENE (1,2-DIMETHYLBENZENE)	ND	0.289	1	µG/L	U	
69MW1603A	04/21/99	172.5	WA	SW8260	TETRACHLOROETHENE(PCE)	ND	0.288	1	µG/L	U	
69MW1603A	04/21/99	172.5	WA	SW8260	TOLUENE	ND	0.197	1	µG/L	U	
69MW1603A	04/21/99	172.5	WA	SW8260	TRANS-1,2-DICHLOROETHENE	ND	0.168	1	µG/L	U	
69MW1603A	04/21/99	172.5	WA	SW8260	TRICHLOROETHENE(TCE)	ND	0.322	1	µG/L	U	
69MW1603A	04/21/99	182.5	WA	SW8260	1,1,1-TRICHLOROETHANE	ND	0.328	1	µG/L	U	
69MW1603A	04/21/99	182.5	WA	SW8260	1,1-DICHLOROETHENE	ND	0.532	1	µG/L	U	
69MW1603A	04/21/99	182.5	WA	SW8260	BENZENE	ND	0.371	1	µG/L	U	
69MW1603A	04/21/99	182.5	WA	SW8260	CARBON TETRACHLORIDE	ND	0.222	1	µG/L	U	
69MW1603A	04/21/99	182.5	WA	SW8260	CIS-1,2-DICHLOROETHENE	ND	0.215	1	µG/L	U	
69MW1603A	04/21/99	182.5	WA	SW8260	ETHYLBENZENE	ND	0.282	1	µG/L	U	
69MW1603A	04/21/99	182.5	WA	SW8260	M,P-XYLENE (SUM OF ISOMERS)	ND	0.406	1	µG/L	U	
69MW1603A	04/21/99	182.5	WA	SW8260	O-XYLENE (1,2-DIMETHYLBENZENE)	ND	0.289	1	µG/L	U	
69MW1603A	04/21/99	182.5	WA	SW8260	TETRACHLOROETHENE(PCE)	ND	0.288	1	µG/L	U	

Volatile Organic Compound Analysis of Borehole Water Samples From New FS-29 Wells

Location	Date	Depth	Matrix	Test	Analyte	Result	DL	RL	Units	Qual	
69MW1603A	04/21/99	182.5	WA	SW8260	TOLUENE	ND	0.197	1	µG/L	U	
69MW1603A	04/21/99	182.5	WA	SW8260	TRANS-1,2-DICHLOROETHENE	ND	0.168	1	µG/L	U	
69MW1603A	04/21/99	182.5	WA	SW8260	TRICHLOROETHENE(TCE)	ND	0.322	1	µG/L	U	
69MW1603A	04/21/99	192.5	WA	SW8260	1,1,1-TRICHLOROETHANE	ND	0.328	1	µG/L	U	
69MW1603A	04/21/99	192.5	WA	SW8260	1,1-DICHLOROETHENE	ND	0.532	1	µG/L	U	
69MW1603A	04/21/99	192.5	WA	SW8260	BENZENE	ND	0.371	1	µG/L	U	
69MW1603A	04/21/99	192.5	WA	SW8260	CARBON TETRACHLORIDE	ND	0.222	1	µG/L	U	
69MW1603A	04/21/99	192.5	WA	SW8260	CIS-1,2-DICHLOROETHENE	ND	0.215	1	µG/L	U	
69MW1603A	04/21/99	192.5	WA	SW8260	ETHYLBENZENE	ND	0.282	1	µG/L	U	
69MW1603A	04/21/99	192.5	WA	SW8260	M,P-XYLENE (SUM OF ISOMERS)	ND	0.406	1	µG/L	U	
69MW1603A	04/21/99	192.5	WA	SW8260	O-XYLENE (1,2-DIMETHYLBENZENE)	ND	0.289	1	µG/L	U	
69MW1603A	04/21/99	192.5	WA	SW8260	TETRACHLOROETHENE(PCE)	ND	0.288	1	µG/L	U	
69MW1603A	04/21/99	192.5	WA	SW8260	TOLUENE	ND	0.197	1	µG/L	U	
69MW1603A	04/21/99	192.5	WA	SW8260	TRANS-1,2-DICHLOROETHENE	ND	0.168	1	µG/L	U	
69MW1603A	04/21/99	192.5	WA	SW8260	TRICHLOROETHENE(TCE)	ND	0.322	1	µG/L	U	
69MW1603A	04/21/99	202.5	WA	SW8260	1,1,1-TRICHLOROETHANE	ND	0.328	1	µG/L	U	
69MW1603A	04/21/99	202.5	WA	SW8260	1,1-DICHLOROETHENE	ND	0.532	1	µG/L	U	
69MW1603A	04/21/99	202.5	WA	SW8260	BENZENE	ND	0.371	1	µG/L	U	
69MW1603A	04/21/99	202.5	WA	SW8260	CARBON TETRACHLORIDE	ND	0.222	1	µG/L	U	
69MW1603A	04/21/99	202.5	WA	SW8260	CIS-1,2-DICHLOROETHENE	ND	0.215	1	µG/L	U	
69MW1603A	04/21/99	202.5	WA	SW8260	ETHYLBENZENE	ND	0.282	1	µG/L	U	
69MW1603A	04/21/99	202.5	WA	SW8260	M,P-XYLENE (SUM OF ISOMERS)	ND	0.406	1	µG/L	U	
69MW1603A	04/21/99	202.5	WA	SW8260	O-XYLENE (1,2-DIMETHYLBENZENE)	ND	0.289	1	µG/L	U	
69MW1603A	04/21/99	202.5	WA	SW8260	TETRACHLOROETHENE(PCE)	ND	0.288	1	µG/L	U	
69MW1603A	04/21/99	202.5	WA	SW8260	TOLUENE	ND	0.197	1	µG/L	U	
69MW1603A	04/21/99	202.5	WA	SW8260	TRANS-1,2-DICHLOROETHENE	ND	0.168	1	µG/L	U	
69MW1603A	04/21/99	202.5	WA	SW8260	TRICHLOROETHENE(TCE)	ND	0.322	1	µG/L	U	
69MW1603A	04/21/99	212.5	WA	SW8260	1,1,1-TRICHLOROETHANE	ND	0.328	1	µG/L	U	
69MW1603A	04/21/99	212.5	WA	SW8260	1,1,1-TRICHLOROETHANE	ND	0.328	1	µG/L	U	duplicate
69MW1603A	04/21/99	212.5	WA	SW8260	1,1-DICHLOROETHENE	ND	0.532	1	µG/L	U	
69MW1603A	04/21/99	212.5	WA	SW8260	1,1-DICHLOROETHENE	ND	0.532	1	µG/L	U	duplicate
69MW1603A	04/21/99	212.5	WA	SW8260	BENZENE	ND	0.371	1	µG/L	U	
69MW1603A	04/21/99	212.5	WA	SW8260	BENZENE	ND	0.371	1	µG/L	U	duplicate
69MW1603A	04/21/99	212.5	WA	SW8260	CARBON TETRACHLORIDE	ND	0.222	1	µG/L	U	
69MW1603A	04/21/99	212.5	WA	SW8260	CARBON TETRACHLORIDE	ND	0.222	1	µG/L	U	duplicate
69MW1603A	04/21/99	212.5	WA	SW8260	CIS-1,2-DICHLOROETHENE	ND	0.215	1	µG/L	U	
69MW1603A	04/21/99	212.5	WA	SW8260	CIS-1,2-DICHLOROETHENE	ND	0.215	1	µG/L	U	duplicate
69MW1603A	04/21/99	212.5	WA	SW8260	ETHYLBENZENE	ND	0.282	1	µG/L	U	
69MW1603A	04/21/99	212.5	WA	SW8260	ETHYLBENZENE	ND	0.282	1	µG/L	U	duplicate

Volatile Organic Compound Analysis of Borehole Water Samples From New FS-29 Wells

Location	Date	Depth	Matrix	Test	Analyte	Result	DL	RL	Units	Qual	
69MW1603A	04/21/99	212.5	WA	SW8260	M,P-XYLENE (SUM OF ISOMERS)	ND	0.406	1	µG/L	U	
69MW1603A	04/21/99	212.5	WA	SW8260	M,P-XYLENE (SUM OF ISOMERS)	ND	0.406	1	µG/L	U	duplicate
69MW1603A	04/21/99	212.5	WA	SW8260	O-XYLENE (1,2-DIMETHYLBENZENE)	ND	0.289	1	µG/L	U	
69MW1603A	04/21/99	212.5	WA	SW8260	O-XYLENE (1,2-DIMETHYLBENZENE)	ND	0.289	1	µG/L	U	duplicate
69MW1603A	04/21/99	212.5	WA	SW8260	TETRACHLOROETHENE(PCE)	ND	0.288	1	µG/L	U	
69MW1603A	04/21/99	212.5	WA	SW8260	TETRACHLOROETHENE(PCE)	ND	0.288	1	µG/L	U	duplicate
69MW1603A	04/21/99	212.5	WA	SW8260	TOLUENE	ND	0.197	1	µG/L	U	
69MW1603A	04/21/99	212.5	WA	SW8260	TOLUENE	ND	0.197	1	µG/L	U	duplicate
69MW1603A	04/21/99	212.5	WA	SW8260	TRANS-1,2-DICHLOROETHENE	ND	0.168	1	µG/L	U	
69MW1603A	04/21/99	212.5	WA	SW8260	TRANS-1,2-DICHLOROETHENE	ND	0.168	1	µG/L	U	duplicate
69MW1603A	04/21/99	212.5	WA	SW8260	TRICHLOROETHENE(TCE)	ND	0.322	1	µG/L	U	
69MW1603A	04/21/99	212.5	WA	SW8260	TRICHLOROETHENE(TCE)	ND	0.322	1	µG/L	U	duplicate
69MW1603A	04/21/99	222.5	WA	SW8260	1,1,1-TRICHLOROETHANE	ND	0.328	1	µG/L	U	
69MW1603A	04/21/99	222.5	WA	SW8260	1,1-DICHLOROETHENE	ND	0.532	1	µG/L	U	
69MW1603A	04/21/99	222.5	WA	SW8260	BENZENE	ND	0.371	1	µG/L	U	
69MW1603A	04/21/99	222.5	WA	SW8260	CARBON TETRACHLORIDE	ND	0.222	1	µG/L	U	
69MW1603A	04/21/99	222.5	WA	SW8260	CIS-1,2-DICHLOROETHENE	ND	0.215	1	µG/L	U	
69MW1603A	04/21/99	222.5	WA	SW8260	ETHYLBENZENE	ND	0.282	1	µG/L	U	
69MW1603A	04/21/99	222.5	WA	SW8260	M,P-XYLENE (SUM OF ISOMERS)	ND	0.406	1	µG/L	U	
69MW1603A	04/21/99	222.5	WA	SW8260	O-XYLENE (1,2-DIMETHYLBENZENE)	ND	0.289	1	µG/L	U	
69MW1603A	04/21/99	222.5	WA	SW8260	TETRACHLOROETHENE(PCE)	ND	0.288	1	µG/L	U	
69MW1603A	04/21/99	222.5	WA	SW8260	TOLUENE	ND	0.197	1	µG/L	U	
69MW1603A	04/21/99	222.5	WA	SW8260	TRANS-1,2-DICHLOROETHENE	ND	0.168	1	µG/L	U	
69MW1603A	04/21/99	222.5	WA	SW8260	TRICHLOROETHENE(TCE)	ND	0.322	1	µG/L	U	
69MW1603A	04/21/99	232.5	WA	SW8260	1,1,1-TRICHLOROETHANE	ND	0.328	1	µG/L	U	
69MW1603A	04/21/99	232.5	WA	SW8260	1,1-DICHLOROETHENE	ND	0.532	1	µG/L	U	
69MW1603A	04/21/99	232.5	WA	SW8260	BENZENE	ND	0.371	1	µG/L	U	
69MW1603A	04/21/99	232.5	WA	SW8260	CARBON TETRACHLORIDE	ND	0.222	1	µG/L	U	
69MW1603A	04/21/99	232.5	WA	SW8260	CIS-1,2-DICHLOROETHENE	ND	0.215	1	µG/L	U	
69MW1603A	04/21/99	232.5	WA	SW8260	ETHYLBENZENE	ND	0.282	1	µG/L	U	
69MW1603A	04/21/99	232.5	WA	SW8260	M,P-XYLENE (SUM OF ISOMERS)	ND	0.406	1	µG/L	U	
69MW1603A	04/21/99	232.5	WA	SW8260	O-XYLENE (1,2-DIMETHYLBENZENE)	ND	0.289	1	µG/L	U	
69MW1603A	04/21/99	232.5	WA	SW8260	TETRACHLOROETHENE(PCE)	ND	0.288	1	µG/L	U	
69MW1603A	04/21/99	232.5	WA	SW8260	TOLUENE	ND	0.197	1	µG/L	U	
69MW1603A	04/21/99	232.5	WA	SW8260	TRANS-1,2-DICHLOROETHENE	ND	0.168	1	µG/L	U	
69MW1603A	04/21/99	232.5	WA	SW8260	TRICHLOROETHENE(TCE)	ND	0.322	1	µG/L	U	
69MW1603A	04/21/99	242.5	WA	SW8260	1,1,1-TRICHLOROETHANE	ND	0.328	1	µG/L	U	
69MW1603A	04/21/99	242.5	WA	SW8260	1,1-DICHLOROETHENE	ND	0.532	1	µG/L	U	
69MW1603A	04/21/99	242.5	WA	SW8260	BENZENE	ND	0.371	1	µG/L	U	

Volatile Organic Compound Analysis of Borehole Water Samples From New FS-29 Wells

Location	Date	Depth	Matrix	Test	Analyte	Result	DL	RL	Units	Qual	
69MW1603A	04/21/99	242.5	WA	SW8260	CARBON TETRACHLORIDE	ND	0.222	1	µG/L	U	
69MW1603A	04/21/99	242.5	WA	SW8260	CIS-1,2-DICHLOROETHENE	ND	0.215	1	µG/L	U	
69MW1603A	04/21/99	242.5	WA	SW8260	ETHYLBENZENE	ND	0.282	1	µG/L	U	
69MW1603A	04/21/99	242.5	WA	SW8260	M,P-XYLENE (SUM OF ISOMERS)	ND	0.406	1	µG/L	U	
69MW1603A	04/21/99	242.5	WA	SW8260	O-XYLENE (1,2-DIMETHYLBENZENE)	ND	0.289	1	µG/L	U	
69MW1603A	04/21/99	242.5	WA	SW8260	TETRACHLOROETHENE(PCE)	ND	0.288	1	µG/L	U	
69MW1603A	04/21/99	242.5	WA	SW8260	TOLUENE	ND	0.197	1	µG/L	U	
69MW1603A	04/21/99	242.5	WA	SW8260	TRANS-1,2-DICHLOROETHENE	ND	0.168	1	µG/L	U	
69MW1603A	04/21/99	242.5	WA	SW8260	TRICHLOROETHENE(TCE)	ND	0.322	1	µG/L	U	
69MW1603A	04/21/99	252.5	WA	SW8260	1,1,1-TRICHLOROETHANE	ND	0.328	1	µG/L	U	
69MW1603A	04/21/99	252.5	WA	SW8260	1,1-DICHLOROETHENE	ND	0.532	1	µG/L	U	
69MW1603A	04/21/99	252.5	WA	SW8260	BENZENE	ND	0.371	1	µG/L	U	
69MW1603A	04/21/99	252.5	WA	SW8260	CARBON TETRACHLORIDE	ND	0.222	1	µG/L	U	
69MW1603A	04/21/99	252.5	WA	SW8260	CIS-1,2-DICHLOROETHENE	ND	0.215	1	µG/L	U	
69MW1603A	04/21/99	252.5	WA	SW8260	ETHYLBENZENE	ND	0.282	1	µG/L	U	
69MW1603A	04/21/99	252.5	WA	SW8260	M,P-XYLENE (SUM OF ISOMERS)	ND	0.406	1	µG/L	U	
69MW1603A	04/21/99	252.5	WA	SW8260	O-XYLENE (1,2-DIMETHYLBENZENE)	ND	0.289	1	µG/L	U	
69MW1603A	04/21/99	252.5	WA	SW8260	TETRACHLOROETHENE(PCE)	ND	0.288	1	µG/L	U	
69MW1603A	04/21/99	252.5	WA	SW8260	TOLUENE	ND	0.197	1	µG/L	U	
69MW1603A	04/21/99	252.5	WA	SW8260	TRANS-1,2-DICHLOROETHENE	ND	0.168	1	µG/L	U	
69MW1603A	04/21/99	252.5	WA	SW8260	TRICHLOROETHENE(TCE)	ND	0.322	1	µG/L	U	
69MW1603A	04/22/99	262.5	WA	SW8260	1,1,1-TRICHLOROETHANE	ND	0.328	1	µG/L	U	
69MW1603A	04/22/99	262.5	WA	SW8260	1,1-DICHLOROETHENE	ND	0.532	1	µG/L	U	
69MW1603A	04/22/99	262.5	WA	SW8260	BENZENE	ND	0.371	1	µG/L	U	
69MW1603A	04/22/99	262.5	WA	SW8260	CARBON TETRACHLORIDE	ND	0.222	1	µG/L	U	
69MW1603A	04/22/99	262.5	WA	SW8260	CIS-1,2-DICHLOROETHENE	ND	0.215	1	µG/L	U	
69MW1603A	04/22/99	262.5	WA	SW8260	ETHYLBENZENE	ND	0.282	1	µG/L	U	
69MW1603A	04/22/99	262.5	WA	SW8260	M,P-XYLENE (SUM OF ISOMERS)	ND	0.406	1	µG/L	U	
69MW1603A	04/22/99	262.5	WA	SW8260	O-XYLENE (1,2-DIMETHYLBENZENE)	ND	0.289	1	µG/L	U	
69MW1603A	04/22/99	262.5	WA	SW8260	TETRACHLOROETHENE(PCE)	ND	0.288	1	µG/L	U	
69MW1603A	04/22/99	262.5	WA	SW8260	TOLUENE	ND	0.197	1	µG/L	U	
69MW1603A	04/22/99	262.5	WA	SW8260	TRANS-1,2-DICHLOROETHENE	ND	0.168	1	µG/L	U	
69MW1603A	04/22/99	262.5	WA	SW8260	TRICHLOROETHENE(TCE)	ND	0.322	1	µG/L	U	

Ethylene Dibromide Analysis of Borehole Water Samples From New FS-29 Wells

Location	Date	Depth	Matrix	Test	Analyte	Result	DL	RL	Units	Qual	
69MW1601A	04/01/99	112.5	WA	E504	1,2-DIBROMOETHANE (EDB)	ND	0.005	0.01	µG/L	U	
69MW1601A	04/01/99	122.5	WA	E504	1,2-DIBROMOETHANE (EDB)	ND	0.005	0.01	µG/L	U	
69MW1601A	04/01/99	132.5	WA	E504	1,2-DIBROMOETHANE (EDB)	ND	0.005	0.01	µG/L	U	
69MW1601A	04/01/99	142.5	WA	E504	1,2-DIBROMOETHANE (EDB)	ND	0.005	0.01	µG/L	U	
69MW1601A	04/01/99	152.5	WA	E504	1,2-DIBROMOETHANE (EDB)	ND	0.005	0.01	µG/L	U	
69MW1601A	04/01/99	162.5	WA	E504	1,2-DIBROMOETHANE (EDB)	ND	0.005	0.01	µG/L	U	
69MW1601A	04/01/99	172.5	WA	E504	1,2-DIBROMOETHANE (EDB)	ND	0.005	0.01	µG/L	U	
69MW1601A	04/01/99	182.5	WA	E504	1,2-DIBROMOETHANE (EDB)	ND	0.005	0.01	µG/L	U	
69MW1601A	04/01/99	192.5	WA	E504	1,2-DIBROMOETHANE (EDB)	ND	0.005	0.01	µG/L	U	
69MW1601A	04/02/99	202.5	WA	E504	1,2-DIBROMOETHANE (EDB)	ND	0.005	0.01	µG/L	U	
69MW1601A	04/02/99	212.5	WA	E504	1,2-DIBROMOETHANE (EDB)	ND	0.005	0.01	µG/L	U	
69MW1601A	04/02/99	222.5	WA	E504	1,2-DIBROMOETHANE (EDB)	ND	0.005	0.01	µG/L	U	
69MW1601A	04/02/99	232.5	WA	E504	1,2-DIBROMOETHANE (EDB)	ND	0.005	0.01	µG/L	U	
69MW1601A	04/02/99	232.5	WA	E504	1,2-DIBROMOETHANE (EDB)	ND	0.005	0.01	µG/L	U	duplicate
69MW1601A	04/02/99	242.5	WA	E504	1,2-DIBROMOETHANE (EDB)	ND	0.005	0.01	µG/L	U	
69MW1601A	04/06/99	252.5	WA	E504	1,2-DIBROMOETHANE (EDB)	ND	0.005	0.01	µG/L	U	
69MW1601A	04/06/99	262.5	WA	E504	1,2-DIBROMOETHANE (EDB)	ND	0.005	0.01	µG/L	U	
69MW1601A	04/06/99	272.5	WA	E504	1,2-DIBROMOETHANE (EDB)	ND	0.005	0.01	µG/L	U	
69MW1602A	04/09/99	82.5	WA	E504	1,2-DIBROMOETHANE (EDB)	ND	0.005	0.01	µG/L	U	
69MW1602A	04/09/99	92.5	WA	E504	1,2-DIBROMOETHANE (EDB)	ND	0.005	0.01	µG/L	U	
69MW1602A	04/09/99	102.5	WA	E504	1,2-DIBROMOETHANE (EDB)	ND	0.005	0.01	µG/L	U	
69MW1602A	04/09/99	102.5	WA	E504	1,2-DIBROMOETHANE (EDB)	ND	0.005	0.01	µG/L	U	duplicate
69MW1602A	04/09/99	112.5	WA	E504	1,2-DIBROMOETHANE (EDB)	ND	0.005	0.01	µG/L	U	
69MW1602A	04/09/99	122.5	WA	E504	1,2-DIBROMOETHANE (EDB)	ND	0.005	0.01	µG/L	U	
69MW1602A	04/09/99	132.5	WA	E504	1,2-DIBROMOETHANE (EDB)	ND	0.005	0.01	µG/L	U	
69MW1602A	04/09/99	142.5	WA	E504	1,2-DIBROMOETHANE (EDB)	ND	0.005	0.01	µG/L	U	
69MW1602A	04/09/99	152.5	WA	E504	1,2-DIBROMOETHANE (EDB)	ND	0.005	0.01	µG/L	U	
69MW1602A	04/09/99	162.5	WA	E504	1,2-DIBROMOETHANE (EDB)	ND	0.005	0.01	µG/L	U	
69MW1602A	04/09/99	172.5	WA	E504	1,2-DIBROMOETHANE (EDB)	ND	0.005	0.01	µG/L	U	
69MW1602A	04/12/99	182.5	WA	E504	1,2-DIBROMOETHANE (EDB)	ND	0.005	0.01	µG/L	U	
69MW1602A	04/12/99	192.5	WA	E504	1,2-DIBROMOETHANE (EDB)	ND	0.005	0.01	µG/L	U	
69MW1602A	04/12/99	202.5	WA	E504	1,2-DIBROMOETHANE (EDB)	ND	0.005	0.01	µG/L	U	
69MW1602A	04/12/99	202.5	WA	E504	1,2-DIBROMOETHANE (EDB)	ND	0.005	0.01	µG/L	U	duplicate
69MW1602A	04/12/99	212.5	WA	E504	1,2-DIBROMOETHANE (EDB)	ND	0.005	0.01	µG/L	U	
69MW1602A	04/12/99	222.5	WA	E504	1,2-DIBROMOETHANE (EDB)	ND	0.005	0.01	µG/L	U	
69MW1602A	04/12/99	232.5	WA	E504	1,2-DIBROMOETHANE (EDB)	ND	0.005	0.01	µG/L	U	
69MW1602A	04/12/99	242.5	WA	E504	1,2-DIBROMOETHANE (EDB)	ND	0.005	0.01	µG/L	U	

Ethylene Dibromide Analysis of Borehole Water Samples From New FS-29 Wells

Location	Date	Depth	Matrix	Test	Analyte	Result	DL	RL	Units	Qual	
69MW1602A	04/12/99	262.5	WA	E504	1,2-DIBROMOETHANE (EDB)	ND	0.005	0.01	µG/L	U	
69MW1603A	04/20/99	92.5	WA	E504	1,2-DIBROMOETHANE (EDB)	ND	0.005	0.01	µG/L	U	
69MW1603A	04/20/99	102.5	WA	E504	1,2-DIBROMOETHANE (EDB)	ND	0.005	0.01	µG/L	U	
69MW1603A	04/20/99	112.5	WA	E504	1,2-DIBROMOETHANE (EDB)	ND	0.005	0.01	µG/L	U	
69MW1603A	04/20/99	112.5	WA	E504	1,2-DIBROMOETHANE (EDB)	ND	0.005	0.01	µG/L	U	duplicate
69MW1603A	04/20/99	122.5	WA	E504	1,2-DIBROMOETHANE (EDB)	ND	0.005	0.01	µG/L	U	
69MW1603A	04/20/99	132.5	WA	E504	1,2-DIBROMOETHANE (EDB)	ND	0.005	0.01	µG/L	U	
69MW1603A	04/20/99	142.5	WA	E504	1,2-DIBROMOETHANE (EDB)	ND	0.005	0.01	µG/L	U	
69MW1603A	04/20/99	152.5	WA	E504	1,2-DIBROMOETHANE (EDB)	ND	0.005	0.01	µG/L	U	
69MW1603A	04/20/99	162.5	WA	E504	1,2-DIBROMOETHANE (EDB)	ND	0.005	0.01	µG/L	U	
69MW1603A	04/21/99	172.5	WA	E504	1,2-DIBROMOETHANE (EDB)	ND	0.005	0.01	µG/L	U	
69MW1603A	04/21/99	182.5	WA	E504	1,2-DIBROMOETHANE (EDB)	ND	0.005	0.01	µG/L	U	
69MW1603A	04/21/99	192.5	WA	E504	1,2-DIBROMOETHANE (EDB)	ND	0.005	0.01	µG/L	U	
69MW1603A	04/21/99	202.5	WA	E504	1,2-DIBROMOETHANE (EDB)	ND	0.005	0.01	µG/L	U	
69MW1603A	04/21/99	212.5	WA	E504	1,2-DIBROMOETHANE (EDB)	ND	0.005	0.01	µG/L	U	
69MW1603A	04/21/99	212.5	WA	E504	1,2-DIBROMOETHANE (EDB)	ND	0.005	0.01	µG/L	U	duplicate
69MW1603A	04/21/99	222.5	WA	E504	1,2-DIBROMOETHANE (EDB)	ND	0.005	0.01	µG/L	U	
69MW1603A	04/21/99	232.5	WA	E504	1,2-DIBROMOETHANE (EDB)	ND	0.005	0.01	µG/L	U	
69MW1603A	04/21/99	242.5	WA	E504	1,2-DIBROMOETHANE (EDB)	ND	0.005	0.01	µG/L	U	
69MW1603A	04/21/99	252.5	WA	E504	1,2-DIBROMOETHANE (EDB)	ND	0.005	0.01	µG/L	U	
69MW1603A	04/22/99	262.5	WA	E504	1,2-DIBROMOETHANE (EDB)	ND	0.005	0.01	µG/L	U	

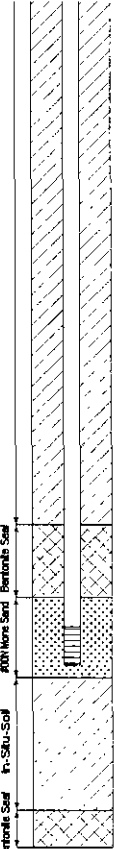


**LOC ID: 69MW1601A**

[illegible]

**LOC ID: 69MW1601A**

SWOU

Project Name: SWOU									Location: Cairn Ridge Road, Falmouth, MA						
Project Number: 35Q86101					Northing: 230634.75					Easting: 844158.29					
Depth (ft-bgs)	Sample ID	Interval (ft.)	Headspace (ppm)	Purge Vol. (gal)	Purge Rate (gpm)	Temperature (c)	pH (units)	ORP (mV)	Conductivity (µS/cm)	Dissolved Oxygen (mg/L)	Turbidity (NTU)	Remarks	Well Construction Diagram	Elevation (ft msl)	
165														-50	
170	OT-D659001	▲ ▼	0.0	465.0	12.5	10.88	6.26	170.6	68.0	12.55	10.9	MS/MSD		-55	
175	OT-D659002													-60	
180	OT-D659003	▲ ▼	0.0	465.0	12.5	10.87	6.22	175.2	76.0	15.87	5.7			-65	
185	OT-D659004													-70	
190	OT-D659101	▲ ▼	0.0	465.0	13.5	10.80	6.24	184.0	70.0	12.76	3.2			-75	
195	OT-D659102													-80	
200	OT-D659201	▲ ▼	0.0	465.0	11.5	10.53	8.52	59.6	101.0	12.37	1.1	Equipment Blank		-85	
205	OT-D659202													-90	
210	OT-D659203	▲ ▼	0.0	520.0	12.0	10.62	5.86	121.5	77.0	13.81	7.3			-95	
215	OT-D659204												-100		
220	OT-D660001	▲ ▼	0.0	465.0	13.5	10.42	5.79	114.6	72.0	12.15	1.8		-105		
225	OT-D660002												-110		
230	OT-D660003	▲ ▼	0.0	465.0	15.0	10.67	6.00	124.0	68.0	11.36	29.4	Field Duplicate	-115		
235	OT-D660004												-120		
240	OT-D660005	▲ ▼	0.0	465.0	13.0	11.47	6.28	127.6	71.0	10.58	153.0		-125		
245	OT-D660101												-130		
250	OT-D660102	▲ ▼	0.0	644.0	14.0	10.89	7.38	151.1	102.0	6.63	23.3	YSI#11046	-135		
255	OT-D660201												-140		
260	OT-D660202	▲ ▼	0.0	465.0	14.0	11.23	6.64	117.1	110.0	5.79	20.2		-145		
265	OT-D660203												-150		
270	OT-D660601	▲ ▼	0.0	475.0	13.0	11.78	6.85	53.0	120.0	7.27	30.9	Top of bedrock at 276 ft. bgs.	-155		
275	OT-D660602												-160		
280													-165		
285													-170		
290													-175		
295													-180		
300													-185		
305													-190		
310													-195		
315													-200		
320													-205		
325													-210		
330													-215		
335													-220		

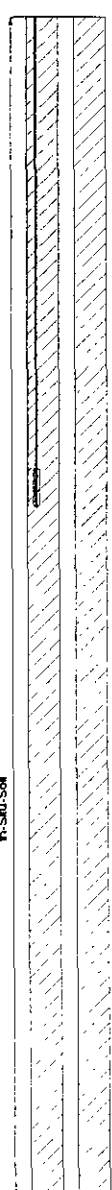
Notes:

- Well Depth 255.25 ft. bgs
- SCH 80 PVC
- Screen length 5.00 feet
- Screen Interval 250.00 - 255.00 ft. bgs
- Slot Size 0.010 in.
- PZ Screen Interval 92.00 - 97.00 ft. bgs

Printed on 06/18/99

LOC ID: 69MW1602A

SWOU

Project Name: SWOU										Location: Longshank Circle, Falmouth, MA																													
Project Number: 35Q86101										Northing: 231556.50										Easting: 843680.95																			
Drilling Contractor: Boart Longyear										Elevation ft (MSL): 89.45										Measuring Point: Top PVC																			
Drilling Equipment: GP24-300RS										Date Started: 04/08/99										Date Finished: 04/14/99																			
Drilling Method: Rotosonic Drill										Total Depth Drilled ft (BGS): 281.00										First Water ft (BGS): NM																			
Sampling Method: Packer Pump										Borehole Diameter (in.): 8.00										Well Diameter (in.): 2.50																			
Const. Materials SCH 80 PVC										Well Depth ft (BGS): 235.05										Static Water ft (BTOC): 63.68																			
Logged by: M. Wilkey										Reviewed by: R. Quraishi, R.P.G.										Completion: Flushmount										Date Measured: 05/19/99									
Depth (ft-bgs)	Sample ID	Interval (ft.)	Headspace (ppm)	Purge Vol. (gal)	Purge Rate (gpm)	Temperature (c)	pH (units)	ORP (mV)	Conductivity (µS/cm)	Dissolved Oxygen (mg/L)	Turbidity (NTU)	Remarks	Well Construction Diagram	Elevation (ft msl)																									
0												69MW1602A: Sampling begins at 80 ft. bgs. Piezometer set from 61.7-66.7 ft. bgs.		90																									
5														85																									
10														80																									
15														75																									
20														70																									
25														65																									
30														60																									
35														55																									
40														50																									
45														45																									
50														40																									
55														35																									
60														30																									
65														25																									
70														20																									
75														15																									
80	OT-D659301 OT-D659302	▲ ▼ 0.0		300.0	14.0	11.48	7.74	110.3	63.0	12.04	18.1	YSI#12200		10																									
85														5																									
90	OT-D659303 OT-D659304	▲ ▼ 0.0		245.0	13.5	11.23	5.78	144.3	116.0	11.35	17.0			0																									
95														-5																									
100	OT-D659401 OT-D659402 OT-D659403 OT-D659404 OT-D659405 OT-D659406	▲ ▼ 0.0		300.0	13.5	10.67	6.05	112.6	72.0	11.72	1.8	Field Duplicate		-10																									
105														-15																									
110														-20																									
115														-25																									
120	OT-D659501 OT-D659502	▲ ▼ 0.0		245.0	13.0	10.46	6.11	109.6	66.0	11.90	275.1			-30																									
125														-35																									
130	OT-D659503 OT-D659504	▲ ▼ 0.0		245.0	13.0	9.94	6.25	94.5	61.0	11.82	14.7			-40																									
135														-45																									
140	OT-D659601 OT-D659602	▲ ▼ 0.0		245.0	13.0	10.28	6.15	116.8	68.0	12.81	6.1	MS/MSD		-50																									
145														-55																									
150	OT-D659603 OT-D659604	▲ ▼ 0.0		223.0	13.5	10.26	6.14	121.9	69.0	12.12	2.6			-60																									
155														-65																									
160	OT-D659701 OT-D659702	▲ ▼ 0.0		223.0	13.0	10.46	6.04	129.4	70.0	11.71	3.7			-70																									

**LOC ID: 69MW1602A**

SWOU

[illegible]

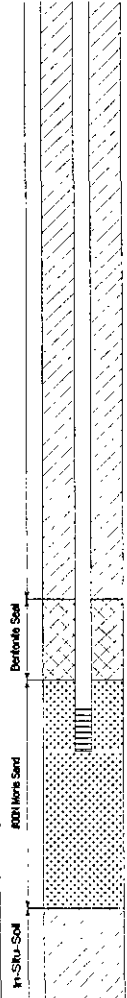
LOC ID: 69MW1603A

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LOC ID: 69MW1603A

SWOU

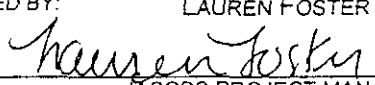
Project Name: SWOU								Location: Route 28 median, Falmouth, MA							
Project Number: 35Q86101								Northing: 232536.72				Easting: 843273.41			
Depth (ft-bgs)	Sample ID	Interval (ft.)	Headspace (ppm)	Purge Vol. (gal)	Purge Rate (gpm)	Temperature (c)	pH (units)	ORP (mV)	Conductivity (µS/cm)	Dissolved Oxygen (mg/L)	Turbidity (NTU)	Remarks	Well Construction Diagram	Elevation (ft msl)	
150	OT-D661801	▲ ▼	0.0	267.0	12.5	10.51	6.09	146.1	73.0	11.48	1.2	MS/MSD		-55	
155	OT-D661802													-60	
160	OT-D661803	▲ ▼	0.0	245.0	14.0	10.28	6.09	156.1	78.0	13.31	4.6			-65	
165	OT-D661804													-70	
170	OT-D661901	▲ ▼	0.0	267.0	13.5	9.84	6.78	161.8	88.0	11.84	4.9	YSI#11170		-75	
175	OT-D661902													-80	
180	OT-D661903	▲ ▼	0.0	300.0	13.5	10.26	6.37	143.5	82.0	10.77	138.2	Equipment Blank		-85	
185	OT-D661904													-90	
190	OT-D662001	▲ ▼	0.0	300.0	11.0	10.57	6.27	181.0	86.0	11.72	15.1			-95	
195	OT-D662002													-100	
200	OT-D662003	▲ ▼	0.0	410.0	11.0	10.45	6.44	154.0	81.0	10.39	32.9	Field Duplicate		-105	
205	OT-D662004													-110	
210	OT-D662101	▲ ▼	0.0	278.0	13.0	12.66	6.65	146.6	72.0	10.37	32.7			-115	
215	OT-D662102													-120	
220	OT-D662103	▲ ▼	0.0	278.0	10.0	12.29	6.59	117.5	77.0	10.13	13.7	Bottom of boring at 272 ft. bgs.		-125	
225	OT-D662104													-130	
230	OT-D662601	▲ ▼	0.0	410.0	12.5	12.01	6.76	124.9	77.0	9.34	212.0		-135		
235	OT-D662602												-140		
240	OT-D662603	▲ ▼	0.0	410.0	13.0	12.13	6.81	129.5	95.0	10.56	204.4		-145		
245	OT-D662604												-150		
250	OT-D662605	▲ ▼	0.0	410.0	13.5	11.82	6.94	116.8	106.0	7.29	203.8		-155		
255	OT-D662606												-160		
260	OT-D662701	▲ ▼	0.0	740.0	9.0	10.73	7.10	-105.1	146.0	3.55	15.3		-165		
265	OT-D662702												-170		
270													-175		
275													-180		
280													-185		
285													-190		
290													-195		
295													-200		
300													-205		
305													-210		
310													-215		
315													-220		
320													-225		

Notes:  
1. Well Depth 240.83 ft. bgs  
2. SCH 80 PVC  
3. Screen length 5.00 feet  
4. Screen Interval  
235.58 - 240.58 ft. bgs  
5. Slot Size 0.010 in.  
6. PZ Screen Interval  
73.89 - 78.89 ft. bgs

Printed on 06/18/99

# **APPENDIX E**

## **Fate and Transport Calculations**

CLIENT, PROJECT AND LOCATION: <b>AFCEE, MMR PLUME RESPONSE PROGRAM SOUTHWEST OPERABLE UNIT OTIS ANG BASE, MASSACHUSETTS</b>		PROJECT NOTE		PROJECT NO. <b>35-Q86101</b>
		NOTE NO. 0101		Page 1 of 11
CONFIRMATION OF: <input type="checkbox"/> MEETING <input type="checkbox"/> TELEPHONE CONVERSATION <input checked="" type="checkbox"/> CALCULATION DESCRIPTION		DATE HELD: n/a LOCATION: n/a DATE ISSUED: 9/30/99 RECORDED BY: DAVID WARD		
SUBJECT: FATE AND TRANSPORT CALCULATIONS FOR THE BASELINE AND PREFERRED ALTERNATIVES FOR THE FS- 28, AND FS-29 PLUMES IN THE SWOU		ISSUED BY: LAUREN FOSTER  JACOBS PROJECT MANAGER		

### INTRODUCTION

This project note examines fate-and-transport simulations of EDB in the SWOU FS-28 and FS-29 plumes for the baseline and preferred alternatives. The baseline scenario assumes no active remediation in any of the SWOU plumes other than the existing systems in CS-4 and at the leading edge of FS-28. The preferred alternative includes replacement of the CS-4 system and additional active remediation in CS-20 and CS-21. These simulations build upon particle-tracking simulations presented in the SWOU FS (AFCEE 1999b) and the FS-28/29 FS (AFCEE 1999a). Particle tracking for the FS-28 plume has been problematic near the FS-28 EW-1 extraction well and the nearby discharge zone along the Coonamessett River. The simulated flow field sweeps to the west around the extraction well, and a narrow stream of particles continues downgradient near the bedrock interface rather than upwelling to the Coonamessett River. Particle tracking for the FS-29 plume has shown that a portion of that plume is captured by extraction wells in the CS-21 plume under the preferred alternative.

In comparison to particle tracking, detailed simulation of these scenarios through fate-and-transport calculations offers a more realistic assessment of plume behavior and duration of remediation. Fate-and-transport modeling calculates the 3-D concentration field as a function of time, permitting examination of parameters such as maximum concentration, remaining plume mass and volume, and concentration at extraction wells. Additionally, fate-and-transport calculations incorporate three important processes affecting concentrations in contaminated groundwater moving through the aquifer:

1. Degradation — a contaminant may be transformed into a different chemical species, either biotically or abiotically.
2. Retardation — a contaminant that reversibly adsorbs on surfaces in the aquifer matrix will move more slowly than the advective flow rate because the adsorbed portion is immobile.
3. Dispersion — because the aquifer matrix is heterogeneous on all scales, an initially sharp concentration front will spread longitudinally, laterally, and vertically. For the FS-28 and FS-29 plumes, molecular diffusion is negligible in comparison to mechanical dispersion, and has been ignored.

Distribution: Lauren Foster, Steve Witzmann, Marty Aker, David Ward  
project files, document control



## MODEL CONFIGURATION

The flow field from the SWOU Zoom Model (AFCEE 1999b) and estimates of the physical values of the above parameters were used as input to the transport section of MODFLOW/SURFACT. Two well configurations served as the basis for the flow field for transport modeling (Figure 1):

- the baseline scenario, consisting of the existing extraction-well fence in the CS-4 plume, the FS-28 EW-1 extraction well, and the Coonamessett water-supply well. Because this scenario is meant to simulate future contaminant distributions, the Crooked Pond water-supply well proposed by the town of Falmouth has also been included.
- the preferred alternative, consisting of remedial systems for the CS-21, CS-20, and CS-4 plumes. The system for CS-21 is based on Scenario 11 of the SWOU FS, and those for CS-20 and CS-4 are based on Scenario 12 (Appendix C, AFCEE 1999b). FS-28 EW-1 and the Coonamessett and Crooked Pond wells are also included, but the CS-4 extraction fence has been deleted.

The coordinates of each of these wells are provided in Table 1. These wells are in addition to those normally present in the Regional Model, and by derivation, the SWOU Zoom Model (AFCEE 1999b). Note, however, that the Coonamessett well is normally present in these models, and that the infiltration beds for the Ashumet Valley sewage treatment plant have been omitted because operations there ceased in 1995.

As part of the SWOU FS, 3-D contaminant distributions were developed for EDB in the FS-28 and FS-29 plumes using the kriging facility in GMS. In preparation for transport modeling, the contaminant distributions were individually mapped onto the irregular grids of the SWOU Zoom Model using MdlSeed (a Jacobs-developed utility). These distributions provided the initial concentrations required for transport modeling, shown in the first time step (time = 0) of each animation. Unlike particle seeds in the SWOU FS and FS-28/29 FS, in which particles representing groundwater with concentrations below the MCL were deleted, these distributions have not been trimmed to MCLs.

Migration of the FS-28 and FS-29 plumes is primarily influenced by the processes of advection and dispersion in response to groundwater flow, by degradation, and by adsorption to the aquifer matrix. On the scale of the SWOU plumes, molecular diffusion is negligible and is not considered here. Thus, the SWOU transport model includes uniform dispersivity values (longitudinal, transverse, and vertical), bulk distribution coefficient ( $K_d$ ) values for EDB describing partitioning, and a degradation half-life for EDB.

A longitudinal dispersivity value of 35 feet was adopted for all the SWOU transport modeling scenarios designed for the above alternatives. This value was obtained as a result of the model calibration conducted for the Ashumet Valley boron plume. According to the results of the same effort, the ratio of transverse to longitudinal dispersivity ratio was 0.1, and the ratio of vertical to longitudinal dispersivity was 0.01. Therefore, the longitudinal, transverse, and vertical dispersivities are 35 ft, 3.5 ft, and 0.35 ft, respectively.

Adsorption is represented in MODFLOW/SURFACT as a linear process wherein the ratio of adsorbed to dissolved contaminant is a constant ( $K_d$ ), independent of concentration. For the contaminants of interest, the value of  $K_d$  can be estimated from the fractional organic carbon content of the sediments ( $f_{oc}$ ) multiplied by laboratory measurements of partitioning between organic carbon and water ( $K_{oc}$ ). As reported in the SWOU RI (AFCEE 1999c),  $f_{oc}$  was assumed to average 0.02 percent. Given average  $K_{oc}$  values of 43.7 for EDB,  $K_d$  was calculated to be 0.0087 mL/g.

For EDB, a half-life of 7 yr was assumed, extrapolated from a field investigation in Florida. The observed degradation rate was diminished to account for the effect of the cooler groundwater of Cape Cod. Further discussion may be found in Project Note AFC-J23-35Q86101-P1-0071.

Two other parameters bearing on the transport model are the porosity and the bulk density. An effective porosity of 30 percent throughout the model was also used. This value was used in both the Regional Model and the SWOU Zoom Model (AFCEE 1999b) and has been adopted as a *de facto* standard for other zoom models at MMR. Based on measurements of soil samples, the bulk density for the SWOU plume matrix appears to be approximately 1.88 g/mL. Coupled with the  $K_d$  values, these values give rise to a retardation factor ( $R_f$ ) of 1.05 for EDB.  $R_f$  is the ratio of the velocity of contaminant transport to advection velocity.

To solve the non-linear governing equation of the transport model, a highly accurate mass-conservative numerical method using the second-order Total Variation Diminishing (TVD) scheme for space interpolation and a fully implicit scheme for time weighting was used. Although this method is time-consuming, it is not subject to the numerical instabilities observed in faster but less accurate solution schemes.

These values for dispersivity,  $K_d$ , and half-lives were combined as the optimal parameter set to simulate the baseline scenario and the preferred alternative for EDB. Two sensitivity runs for the preferred alternative were also conducted. In these runs, the effect of dispersivity was removed by setting its associated parameters to 0, and the effect of degradation was removed by setting the half-life to infinity. The estimated  $R_f$  for EDB is already so close to unity that retardation plays a negligible role in EDB transport. Comparisons with optimal runs highlight the effects of dispersion and degradation on the transport of EDB.

## RESULTS

The four model runs are summarized in Table 2. Time-varying contaminant distributions are summarized in three formats: graphs of maximum concentration anywhere within the model versus time (Figure 2), graphs of concentration at each well versus time (Figures 3 and 4), and animations of plume evolution versus time. The first two formats are presented in this project note, whereas the animations are on file at the Jacobs MMR office.

### Maximum-Concentration Graphs

Maximum-concentration graphs are presented in Figure 2. These plots were created by scanning the concentration arrays at each time step in the simulations to find the maximum value. At the same time, the dissolved and total contaminant masses in the model were summed. In these simulations,  $K_d$  is low, so retardation is small and dissolved mass is only slightly less than total mass.

The EDB results reflect the behavior of the FS-28 plume; the FS-29 plume contains negligible mass and disperses to less than the MCL in only a few years. Only the preferred alternative is portrayed in Figure 2; the maximum concentration in the baseline scenario is identical because it depends on only the FS-28 plume, which behaves the same in the two scenarios. With the optimal parameter set, the FS-28 plume reaches the MCL in 41 years (Figure 2a). As part of sensitivity analysis, dispersion was removed from the model. The time to reach the MCL increased only slightly, to 44 years (Figure 2c), consistent with the location of the plume in a zone of converging flow and discharge to the Coonamessett bogs. Eliminating degradation produces a much stronger effect, increasing the time to approximately 93 years (Figure 2b).

### Well-Concentration Graphs

Concentration curves versus time for individual wells are portrayed for each run in Figures 7 to 11, in the same order as of the maximum-concentration plots discussed above. These graphs were constructed by scanning the concentration arrays at each time step for the concentration in each cell intersecting a well screen. These cell-by-cell concentrations were weighted by their pumping rates (from the MODFLOW/SURFACT well file for the flow simulation) to obtain the average contaminant concentration in water withdrawn from each well.

In the preferred alternative for EDB (Figure 3), it is clear that FS-28 EW-1 is not properly located with respect to EDB movements in the model. This is reflected by the lack of sensitivity of influent concentration to elimination of degradation, changing the half-life from 7 years to infinity. Instead, the decline in influent concentration occurs because the simulated plume moves to the west, flowing around FS-28 EW-1.

Figure 4 shows EDB concentrations in extraction wells in the CS-21 plume for the preferred alternatives. These wells were placed to intercept TCE in the CS-21 plume, but particle tracking showed that they also intercept some water from the FS-29 plume. However, the concentration of EDB in these wells from fate-and-transport simulations is probably below detectable levels, reaching a maximum of less than 0.0015 µg/L in EW-A4 at 9 years.

## Animations

Animations were created using GMS to graphically render each time step and record the resulting pictures in Windows-format video clips. These are best viewed with the Windows Media Player. Each animation shows a plan view of the 3-D contaminant distribution contoured with isosurfaces of 0.004, 0.02 (the MCL), 0.1, and 0.5 µg/L. A time clock is displayed in the upper right corner, with time units of years or days. GMS does not provide a means of annotating the clock, but the correct time units are easily discerned. GMS draws the isosurfaces in order from lowest to highest, with each successive isosurface overwriting the coincident parts of the earlier isosurface. The result is much like a projection onto the xy plane of the highest concentration in each vertical column of model cells, providing a view of the core of the plume.

Animations of the EDB runs show that the plumes migrate quite slowly, consistent with their depth near the bottom of the aquifer where simulated flow velocities are much smaller than near the water table. In reality, the velocity profile must be more homogeneous. Otherwise, the plume could not have migrated into its present position in the 30 to 40 years of available time. Because of this problem, it is likely that the simulated remediation times are too great by at least a factor of 2. The animations also clearly portray the curve in the flow field that advects the bulk of the plume around the EW-1 well to the west, outside of the present plume footprint. In reality, the flow field is believed to guide the core of the plume directly to EW-1, significantly shortening the travel time for the upgradient portions of the plume.

Performance of the fate-and-transport modeling at the toe of the FS-28 plume, where it discharges to the Coonamessett River, is better than particle tracking. Particle tracks (AFCEE 1999a, b) showed a narrow stream of particles continuing downgradient along the bedrock interface, whereas the fate-and-transport animations indicate that none of the plume travels very far past this discharge zone. In the absence of degradation, the toe of the plume migrates several thousand feet downgradient from its current position, but only at concentrations below the MCL. Although it is likely that dispersion is responsible for this attenuation, this cannot be evaluated from the no-dispersivity case because the effect of dispersion is completely overshadowed by degradation.

For the FS-29 plume, animations show that all groundwater is below the EDB MCL after 10 years for both the baseline scenario and preferred alternative with the optimal parameter set. There is little difference in plume outline under either scenario even though some EDB is captured by the CS-21 extraction wells in preferred alternative. This indicates that mass capture by the CS-21 extraction wells is negligible, consistent with the low simulated EDB concentrations in these wells (Figure 4). Dispersivity also exerts little influence. Instead, disappearance of the plume is primarily a function of degradation. In the absence of degradation, the MCL is not reached until 21 years, and groundwater containing EDB below the MCL eventually reaches discharge zones along the coastline of Buzzards Bay. Lack of degradation also effects the FS-28 plume, allowing it to persist for more than 90 years, rather than 48 years.

## SUMMARY

Simulations incorporating the three most important transport processes of dispersion, retardation, and degradation provide estimates of the time required to remediate the SWOU plumes that are similar to estimates based on travel time or degradation (hydrolysis) and presented in the SWOU FS (Table 3). Dispersion has a minimal effect on the FS-28 plume, which is located in a converging flow field, whereas, in the absence of degradation, dispersion is probably instrumental in reducing maximum concentrations in the FS-29 plume (cf. the EDBPrefNoDegrad.avi animation). Because its estimated half-life of 7 years is short relative to the life span of the plumes, EDB is quite sensitive to variations in degradation rate. In the absence of degradation, the plumes would persist above the MCL for at least twice as long (90 years versus 48 years for FS-28, or 21 years versus 10 years for FS-29). Thus, the appropriate degradation rate for EDB is one of the major uncertainties in time-dependent modeling of the EDB plumes. Additionally, flow rates in most of the layers of the model are unrealistically slow.

## REFERENCES

AFCEE (U.S. Air Force Center for Environmental Excellence). 1999a (July). *Draft FS-28 and FS-29 Groundwater Feasibility Study*. AFC-J23-35Q86101-M16-0008. Prepared by Jacobs Engineering Group Inc. for AFCEE/MMR Installation Restoration Program, Otis ANGB, MA.

----- . 1999b (June). *Final Southwest Operable Unit Feasibility Study*. AFC-J23-35Q86101-M16-0006. Prepared by Jacobs Engineering Group Inc. for AFCEE/MMR Installation Restoration Program, Otis ANGB, MA.

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GMS (U.S. Department of Defense Groundwater Modeling System) Version 2.1. Provo, UT: Brigham Young University. 1998.

MODFLOW/SURFACT Version 1.2. Herndon, VA: HydroGeoLogic, Inc. 1996.

## TABLES

**Table 1. Extraction wells and infiltration galleries added to the standard set of wells in the 1999 Regional Model and SWOU Zoom Model**

Location	Easting (ft)	Northing (ft)	TOS (ft msl)	BOS (ft ms)	Q (gpm)	Purpose
<u>Baseline Scenario</u>						
Coonamesett Well	853214.7	226873.0	0.0	-20.0	-403	Existing public water supply
(FS28)EW1	853232.7	224250.1	-107.7	-168.7	-600	Existing FS-28 remediation
Crooked Pond Well	849191.4	226342.6	-8.0	-18.0	-1020	Proposed public water supply
(CS4)EW0004	855640.5	232812.5	-27.4	-42.4	-20	Existing CS-4 extraction well
(CS4)EW0005	855582.8	232829.9	-27.0	-42.0	-20	Existing CS-4 extraction well
(CS4)EW0006	855526.6	232848.9	-26.8	-41.8	-20	Existing CS-4 extraction well
(CS4)EW0007	855468.5	232867.5	-26.9	-41.9	-20	Existing CS-4 extraction well
(CS4)EW0008	855412.0	232886.5	-27.4	-42.4	-20	Existing CS-4 extraction well
(CS4)EW0009	855355.2	232904.9	-27.8	-42.8	-20	Existing CS-4 extraction well
(CS4)EW0010	855298.4	232923.3	-27.9	-42.9	-20	Existing CS-4 extraction well
(CS4)EW0011	855251.9	232960.1	-28.0	-43.0	-20	Existing CS-4 extraction well
(CS4)EW0012	855184.0	232960.9	-28.0	-43.0	-20	Existing CS-4 extraction well
(CS4)EW0013	855126.6	232979.1	-27.7	-42.7	-20	Existing CS-4 extraction well
CS-4 infiltration	859203.0	234953.0	na	na	200	Existing CS-4 infiltration gallery
<u>Preferred Alternative</u>						
Coonamesett Well	853214.7	226873.0	0.0	-20.0	-403	Existing public water supply
(FS28)EW1	853232.7	224250.1	-107.7	-168.7	-600	Existing FS-28 remediation
Crooked Pond Well	849191.4	226342.6	-8.0	-18.0	-1020	Proposed public water supply
EW-A1	846200.0	232710.0	-145.0	-175.0	-300	Proposed CS-21 extraction well
EW-A2	848280.0	233700.0	-102.0	-190.0	-300	Proposed CS-21 extraction well
EW-A3	849790.0	234630.0	-17.0	-56.0	-150	Proposed CS-21 extraction well
EW-A4	849790.0	234630.0	-72.0	-162.0	-150	Proposed CS-21 extraction well
EW-A5	850770.0	235810.0	-16.0	-67.0	-150	Proposed CS-21 extraction well
EW-A6	850770.0	235810.0	-71.0	-135.0	-150	Proposed CS-21 extraction well
EW-B1	852660.0	231540.0	-51.0	-131.0	-167	Proposed CS-20 extraction well
EW-B2	853350.0	233060.0	-51.0	-149.0	-167	Proposed CS-20 extraction well
EW-B3	853930.0	234390.0	-42.0	-142.0	-166	Proposed CS-20 extraction well
EW-C1	854990.0	232000.0	-59.0	-89.0	-100	Proposed CS-4 extraction well
EW-C2	855180.0	233740.0	-48.0	-71.0	-100	Proposed CS-4 extraction well
EW-C3	855170.0	232890.0	-74.0	-105.0	-100	Proposed CS-4 extraction well
IG-A1	846320.0	234200.0	na	na	600	Proposed CS-21 infiltration gallery
IG-A2	851620.0	232850.0	na	na	600	Proposed CS-21 infiltration gallery
IG-B1	849930.0	230830.0	na	na	600	Proposed CS-20 infiltration gallery
CS-4 infiltration	859203.0	234953.0	na	na	200	Existing CS-4 infiltration gallery

### Notes

TOS = top of screen.

BOS = bottom of screen.

Q = pumping rate. Q < 0 indicates extraction, Q > 0 indicates reinjection.

Coonamesett Well – this well is part of the standard set of wells in the 1999 Regional Model and the SWOU Zoom Model.

na = not applicable.

**Table 2. Summary of fate-and-transport runs (optimal parameters and sensitivity analysis)**

	Simulation Parameters				Duration of Remediation	Animation Information		
	Scenario	Kd (mL/g)	Rf	Half-life (yr)	Max < MCL (yr)	Total Run Time (yr)	Time Between Frames (yr)	Video Clip Filename
Contaminant								
<u>Optimal Runs</u>								
EDB	Baseline	0.0087	1.054	7	41	60	2	EDBBaseOpt.avi
EDB	Preferred	0.0087	1.054	7	41	50	2	EDBPrefOpt.avi
<u>No Degradation (half-life = infinity)</u>								
EDB	Preferred	0.0087	1.054	∞	~93	90	3	EDBPrefNoDegrad.avi
<u>No Dispersivity (all dispersion coefficients = 0)</u>								
EDB	Preferred	0.0087	1.054	7	44	50	2	EDBPrefNoDisp.avi

Notes

1. Max = maximum contaminant concentration remaining in groundwater at each time step.
2. When the MCL was not reached within the total run time, the concentration trend was extrapolated to the MCL. The time value is an estimate, as indicated by the -.

**Table 3. Comparison of remediation-time estimates based on transport modeling to estimates derived from particle tracking**

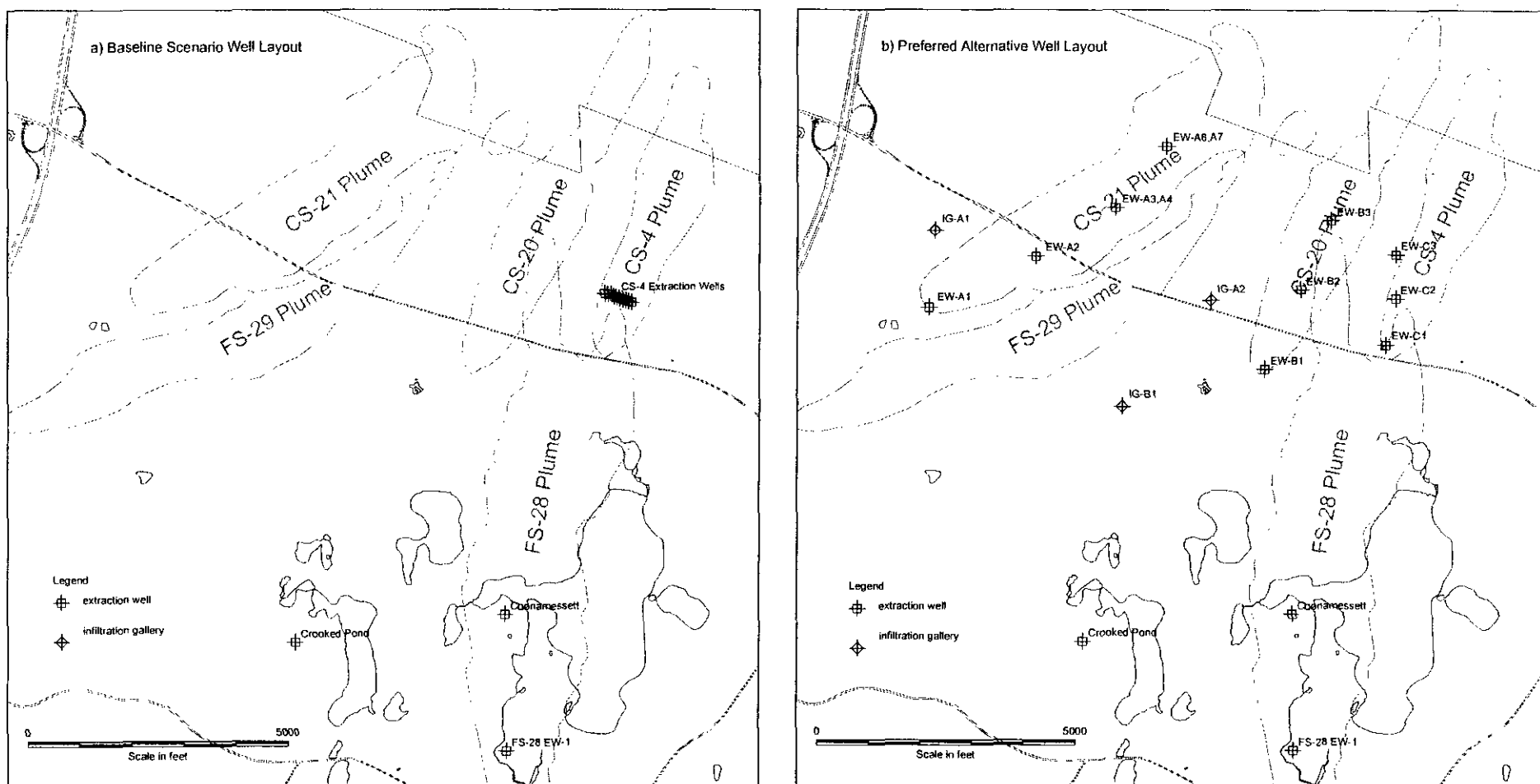
Plume	Baseline Scenario		Preferred Alternative	
	FS (yr)	F&T (yr)	FS (yr)	F&T (yr)
FS-29	10	10	10	10
FS-28	30	40	30	40

Notes

FS = Estimates presented in SWOU Feasibility Study (AFCEE 1999b). They are based on hydrolysis (FS-29) or groundwater travel times (FS-28).

F&T = Estimates from fate-and-transport modeling.

**FIGURES**



**Figure 1. Well layouts. a) Baseline Scenario, b) Preferred Alternative.**

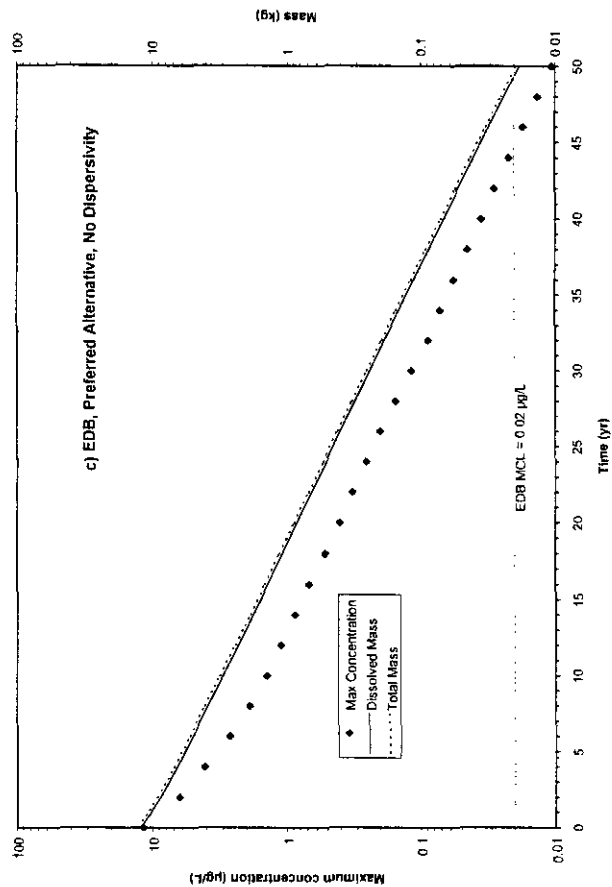
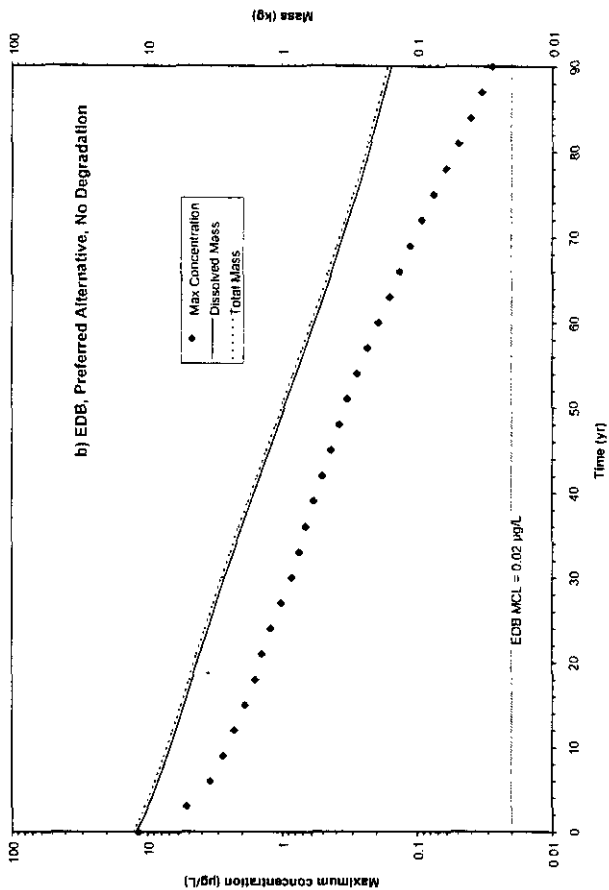
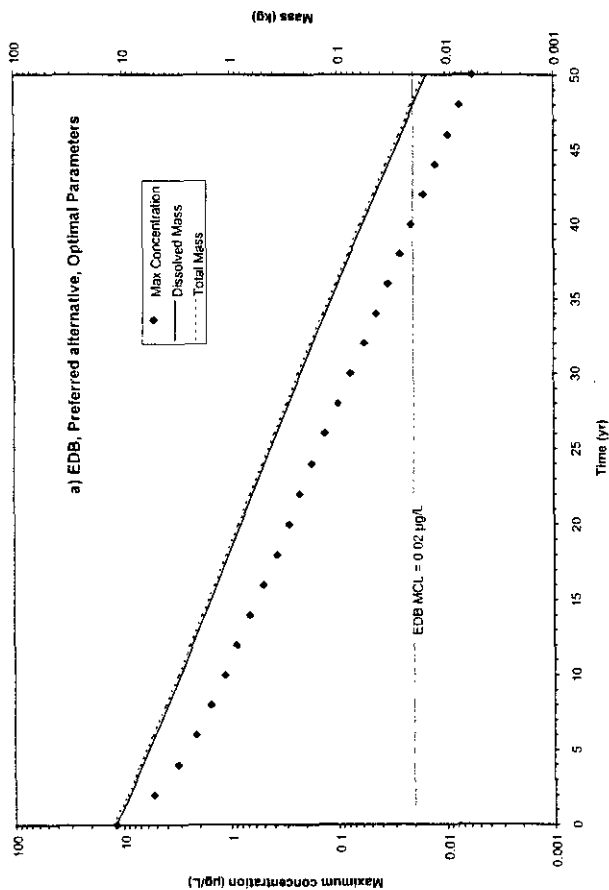


Figure 2. Preferred Alternative maximum EDB concentrations. a) optimal parameters, b) no degradation, c) no dispersivity.



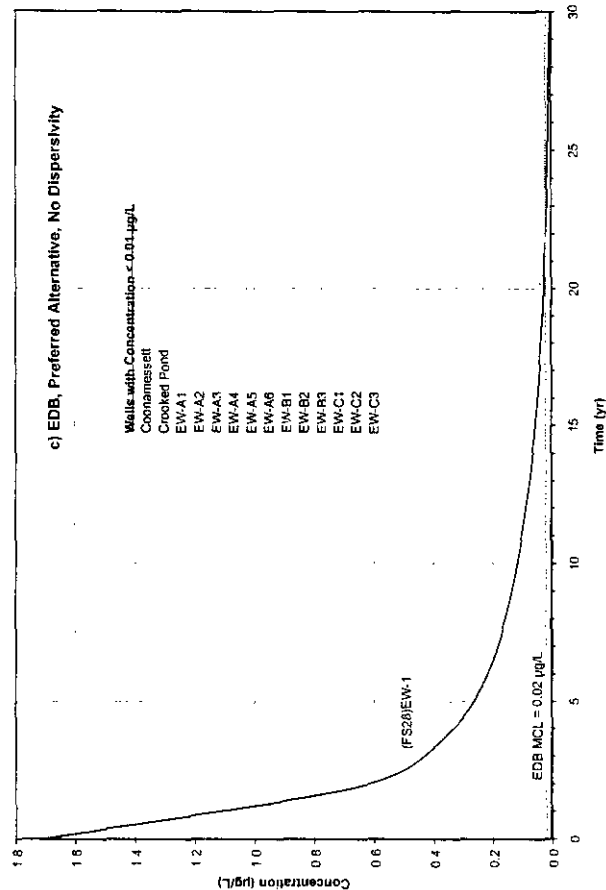
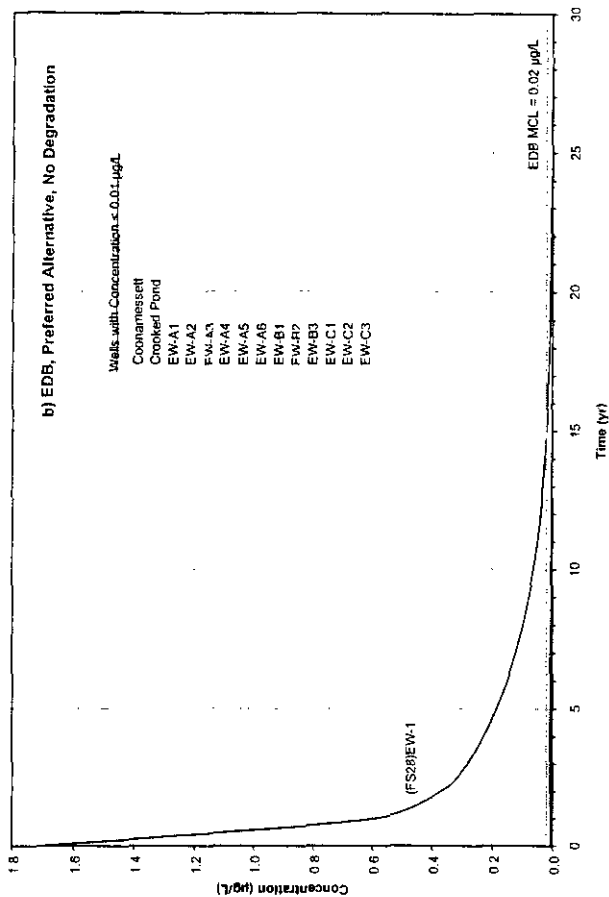
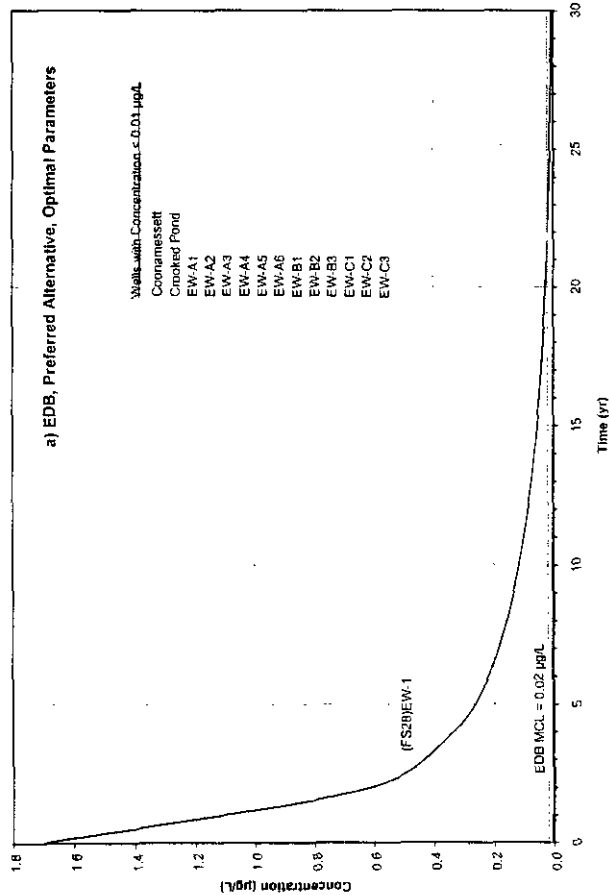


Figure 3. Preferred Alternative EDB well concentrations. a) optimal parameters, b) no degradation, c) no dispersivity.

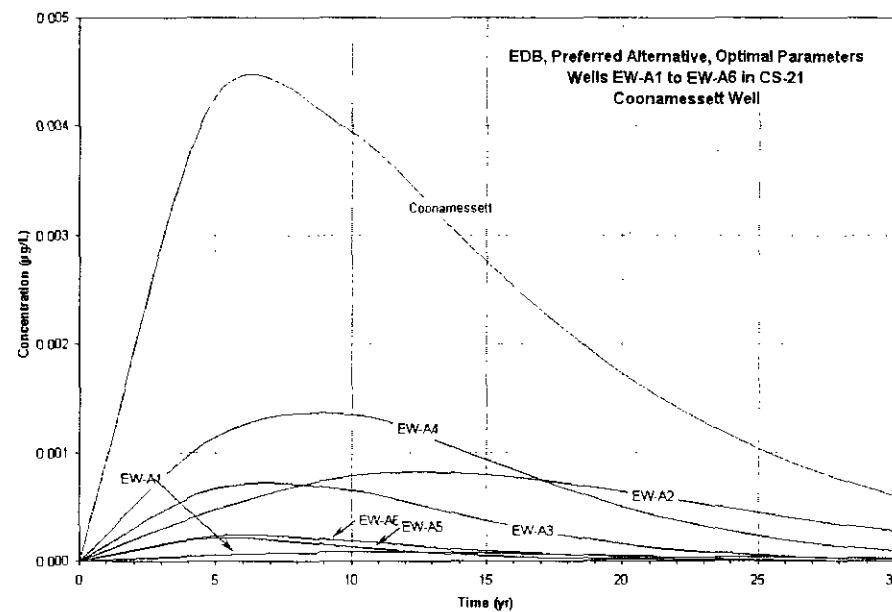


Figure 4. EDB in CS-21 wells for the preferred alternative.

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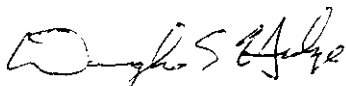
SUBJECT: Contract F41624-97-D-8006  
MMR Plume Response Program  
DO 06 DCN/PROJECT # AFC-J23-35Q86101-M16-0011  
***Final FS-28 and FS-29 Groundwater Feasibility Study***

Dear Mr. Snyder:

As directed by the Air Force Center for Environmental Excellence, Jacobs Engineering Group Inc. is hereby providing 22 bound copies, one unbound copy, and one electronic copy of the above document, dated January 2000. Copies are also being sent to the appropriate agencies.

Please feel free to contact me or Lauren Foster at (508) 564-5746 extension 316, if you have any questions or comments.

Sincerely,



502 Eric W. Banks, P. E.  
Program Manager

EWB/cle

Enclosures: Document (22 bound, 1 unbound & 1 EDD)

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